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WASHABILITY TESTS OF ILLINOIS COALS

CONDUCTED BY

THE ENGINEERING EXPERIMENT STATION
UNIVERSITY OF ILLINOIS

IN COÖPERATION WITH

THE ZEIGLER COAL AND COKE COMPANY

BY

ALFRED C. CALLEN

AND

DAVID R. MITCHELL

BULLETIN No. 217

ENGINEERING EXPERIMENT STATION

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PROFESSOR OF MINING ENGINEERING

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ASSOCIATE IN MINING ENGINEERING

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WASHABILITY TESTS OF ILLINOIS COALS

I. Introduction

1. *Object and Scope of Investigation.*—Previous bulletins* of the Engineering Experiment Station have dealt with coal preparation problems in Illinois. A report of the United States Bureau of Mines† gives results of cleaning tests on a coal from Montgomery County, Illinois, the work being done under a coöperative agreement between the Bureau of Mines, the Engineering Experiment Station, and the State Geological Survey. A report of work done under the same cooperative agreement and by the same authors was issued by the Bureau of Mines (Bulletin 300) late in 1929. For Illinois, it gives data on a coal from Marshall County and on one from Franklin County. Other earlier references give some information, more or less fragmentary, as to the washability of Illinois coal.

In general, however, it may be said that there has been available but little material on the washing characteristics of Illinois coals, and practically none of this material is on the coals of the northern half of the state.

In order to make available a wider and more complete knowledge of Illinois coals, both with respect to their preparation and washability and to their combustion characteristics, the Zeigler Coal and Coke Company of Chicago, by Mr. D. B. Fulton, vice president, entered into a coöperative agreement with the Engineering Experiment Station for the investigation of Illinois coals. This agreement became effective December 1, 1928, and continued for one year.

The part of the investigation pertaining to preparation and washability tests was assigned to the Department of Mining Engineering. The objects were: to select a few typical mines and study the occurrence of visible impurities in the coal, and the nature of the roof and floor; to study the methods of mining, and determine what effect they had on the impurities in the mined coal; to consider the possibilities of hand picking these coals; to secure adequate samples of the mined coal, and make a reasonably complete study of the washability of these coals; to determine the amount and distribution of ash and the different forms of sulphur; to determine yields of washed coal, and the

*"Coal Washing in Illinois," Univ. of Ill. Eng. Exp. Sta. Bul. 69, 1913; "Dry Preparation of Bituminous Coal at Illinois Mines," Univ. of Ill. Eng. Exp. Sta. Bul. 88, 1916.

†Technical Paper 361, "Cleaning Tests of Illinois Coals," by Thomas Fraser and H. F. Yancey, 1925.

limits of the reduction of ash and sulphur percentages; to make some studies of the variation in fusion point of the ash of raw coal and washed coal.

After consultation with the State Geological Survey and the approval of the coöperating agent, the following mines were selected:

Mine A LaSalle County, No. 5 Bed
Mine B* Marshall County, No. 7 Bed
Mine C Peoria County, No. 5 Bed
Mine D† Peoria County, No. 5 Bed
Mine E LaSalle County, No. 2 Bed
Mine F Franklin County, No. 6 Bed (low sulphur area)
Mine G Williamson County, No. 5 Bed

Samples were obtained, studies made, and tests conducted as described in Chapter III.

2. *Acknowledgments.*—The investigation has been part of the regular work of the Engineering Experiment Station of which Dean Milo S. Ketchum is the director, and of the Department of Mining Engineering of which Prof. Alfred C. Callen is the head.

All the details of the investigation were under the immediate supervision of the senior author. The junior author was in charge of the field and laboratory work and of the preparation of data. J. E. Machamer and R. B. Hoover were appointed special research graduate assistants and assigned to this problem, Mr. Machamer carrying on the field work and the float-and-sink tests, while Mr. Hoover made all the chemical analyses.

Grateful acknowledgment is made of the assistance of Dr. G. H. Cady and Mr. C. G. Ball of the State Geological Survey, and of the coöperation of the mining companies and their operating officials.

II. The Preparation of Coal

3. *General Features.*—Coal preparation may be defined as the removal from the coal of part of its separable impurities and the sizing of the coal, both in response to the demands of the market. Thus considered, preparation may begin at the working face as the miner picks out the larger pieces of impurities—bands of shale, sulphur balls, or layers of bone coal. It continues as the coal is treated in the tipple by sizing, by hand picking, or as it is "washed" by wet or dry processes, or as refuse is removed by mechanical appliances.

*Three "country banks" were sampled and the composite sample was treated as Mine B.
†Channel samples only.

It is not the function of this report to deal with coal preparation methods in general nor to consider particular processes, but rather to present the characteristics of Illinois coals as determined by this investigation that affect their washability, and to show the limiting qualities and yields that may be secured by proper preparation. It is possible to give but a brief survey of the problems of coal preparation to serve as an introduction to the consideration of the data presented in this report.

4. *Impurities in Coal and Their Effects.*—From the standpoint of utilization, there are two chief impurities in coal, ash and sulphur.

Not even the purest coal is completely combustible. The plants from which coal was made contained some mineral matter, as do all plants today, and this mineral matter makes up part of the ash of all coals. If the accumulations of vegetal material took place in clear water and with no influx of mud or silt, the coal formed therefrom may be exceptionally low in ash. If small pieces of the cleanest coal have been selected for analysis, or if the purest coal has been separated by floating it on a heavy solution, a very low percentage of ash may be found, perhaps only a fraction of one per cent. If, however, the accumulations were laid down in muddy water, the inherent* ash would be much greater.

As examples of these extremes, the ash in the finer sizes of coals from Mines F and B may be cited. Expressed on a moisture-free basis, the ash in samples floating on a solution of 1.30 specific gravity was: for 20 x 48 mesh coal, for Mine F, 0.86 per cent, for Mine B, 2.95 per cent; for coal through 48 mesh, for Mine F, 0.27 per cent, for Mine B, 2.88 per cent.

In addition to the ash that may be considered to be inherent in a given coal, there may be other ash-forming material in the bed that is not inherent in the coal substance nor deposited concurrently but which was laid down during changing geologic conditions. Thus a band of shale or a layer of "bone coal" perhaps a fraction of an inch or several inches in thickness may be found in the bed, extend-

*The term "inherent ash" has been generally used to denote the ash that is part of the coal substance itself, such ash representing not only the ash from the plant material but also that from the fine silt or slime that accumulated concurrently with the vegetal material. Sometimes this inherent ash has been referred to as "inseparable ash," but this is not a justifiable synonym, for fine crushing will free some of these fine ash-material particles. The term "inherent" refers only to the fact that the coal-forming material was originally a concurrent deposition of vegetal and extraneous mineral matter, and to that extent the ash may be considered inherent. Inseparable ash should be considered only as that ash that cannot be removed from coal of any given size; it may consist either of inherent ash alone or of inherent and interbedded ash. Mott and Wheeler (Fuel in Science and Practice, VI, 9, September, 1927, pp. 416-420) describe the results they secured in separating the extraneous or adventitious ash from the ash representing the mineral constituents of the coal-forming plants. They apply the term "inherent ash" to this latter type only.

ing for miles. Such impurities are called sedimentary or interbedded impurities. Bone coal has some fuel value, for it is customary to call impure layers bone coal if they contain say 50 per cent or more of coal material, but bands or binders containing less than this amount are of no value.

Additional ash-forming material may come into a coal bed after its formation by means of circulating waters carrying salts of sodium, iron, or calcium in solution and depositing them under favorable conditions either as precipitates or replacements. Thus are formed pyrite, whether as nodules, lenses, or flakes, calcite and gypsum, and occasionally halite. Other material that results in ash is represented by the clay that has filled cracks and fissures in the coal, forming "slips," "clay veins" or "mud slips." Such impurities are called subsequent impurities.

Sulphur occurs in coal both as an inherent and as a subsequent impurity. Most, if not all, of the inherent sulphur is in combination with the organic coal substance and so is known as organic sulphur.

Pyrite or marcasite, FeS_2, is the chief source of visible sulphur in coal. In some coals it is the major source of all sulphur. As indicated above, it may be present as nodules, lenses, or flakes. It sometimes occurs in layers or in veins or veinlets. Some coals show considerable microscopic pyrite, most of the particles being less than 0.002 in. in diameter.

Another source of sulphur in coal is gypsum, $CaSO_4$, $2H_2O$, which sometimes occurs as white flakes in the joints or cleavage planes of the coal. As a rule, the amount of sulphur of this kind is small, seldom over 0.2 per cent and frequently less than 0.1 per cent. Such sulphur is called "sulphate sulphur." If the coal is freshly mined, the gypsum will probably be the only source of sulphate sulphur. If the coal has been mined for some time, however, some iron suphate may be formed as the result of the oxidation of pyrite.

All the impurities discussed have been parts of the coal bed. It must be evident, however, that in mining the coal some portions of the roof and floor may be included with the coal loaded into the mine car. Such material is, of course, ash forming, and may introduce additional sulphur.

It might be well to note that ash as reported in a proximate analysis of coal does not represent the percentage of impure material in the coal, but is the incombustible residue left after ignition. The shale constituents lose water of hydration and carbonaceous material on ignition, pyrite loses sulphur and gains oxygen, calcium carbonate loses

carbon dioxide. In every case there is a greater amount of impurities in the coal than is shown by the percentage of ash reported by the chemist. Under most conditions no correction is made for this error, for the numerical value of the correction might easily be less than the variation between samples.

Moisture has not been mentioned as an impurity because it is not of immediate concern in studying the washability of coal. It is, however, an important impurity considered from the standpoint of utilization of the coal. Being incombustible, it reduces directly the heating value of the coal.

Ash produces several deleterious effects. It lowers the heating value directly because it replaces an equal amount of combustible. Its presence means useless expenditure for freight charges on the raw coal, handling costs in utilization and for removal and disposal of the ashes. It also results in lower furnace efficiencies.

If the coal is made into coke, the effects of the ash may be even more serious. Since a ton of coal yields from ⅔ to ¾ ton of coke, the percentage of ash in the coke will be from 1.3 to 1.5 times the percentage in the coal. If the coke is used for metallurgical purposes, say in the blast furnace for the manufacture of pig iron, greater quantities of flux will be required to give a slag of proper composition, more coke will therefore be required and the capacity of the furnace will be decreased.

High sulphur in metallurgical coke is even more objectionable. Sulphur must be kept out of the pig iron by carrying the sulphur into the slag. This requires greater quantities of limestone and a greater consumption of coke per ton of pig iron produced.

Many studies of the economics of ash and sulphur in the blast furnace have been made, but it is not necessary to detail them here. It will be sufficient to give general examples. It has been estimated that a reduction of one in the percentage of ash in the coke means a saving of about 25 cents per ton of pig iron. For each 0.1 reduction in the percentage of sulphur in the coke, a saving may be made of from 15 to 30 cents or more per ton of pig iron.

In the ceramic industry, high-sulphur coals are undesirable for burning certain clay wares, producing discoloration of the ware and glazes. In some cases, a coal as low as one per cent in sulphur is required.

For use in domestic furnaces, coal high in sulphur can be used without much trouble. The same is true of steam coal although in many cases excessive corrosion results from the use of coals high in

sulphur. The exact cause of this is not yet known, but it appears to be due in the main to some effect of the coarser pyritic sulphur.

Other deleterious effects attributed to high sulphur are clinker trouble and spontaneous combustion. Neither of these are invariably or even generally caused by high sulphur.

5. *Factors Affecting Washability.*—In considering whether a coal can be improved by washing or by handpicking, or by any other means, it is necessary that two questions be answered affirmatively:

(1) Can the impurity be loosened from the coal?

(2) Can the freed impurity be separated from the coal?

Simple as these questions may seem, yet many failures have resulted by ignoring or misunderstanding them.

It is quite evident that a large lump of pyrite with attached coal may be loosened by breaking off the coal, and that the lump of pyrite may then be separated from the coal by the simple process of lifting it by hand and throwing it away. In like manner an adhering layer of shale may be freed and separated. Pieces of roof or floor that have been mixed with the mined coal are already free, as a rule, and may be easily removed if they are of sufficient size. For sizes down to about 3 inches such simple methods may suffice unless the impurities are thin layers or veinlets.

For finer sizes, the impurities may have been loosened from the coal by mining and blasting. On the other hand, it may be necessary to crush all or the greater part of the coal to a very small size in order to free the impurities effectively. It must be evident that crushing to very small particles will free all impurities except those that are inherent and those of a smaller size than the crushed particles. While fine crushing may be very undesirable in many cases due to the lack of demand for fine coal, yet the fact remains that with many coals fine crushing may be absolutely necessary to secure maximum freeing. The economical fineness of crushing must be decided for each particular coal.

But after the coal is freed from its attached impurities it must be separable from them if it is to be considered a washable coal. Since the cleanest bituminous coal has a specific gravity of about 1.25-1.40, and since shale and similar impurities have a gravity of from 2.0-2.6, and pyrite a gravity up to 5.2, it is clear that any cleaning process based on differences in specific gravity of coal and impurity would be likely to succeed.

However, there are certain factors that militate against the easy

simplicity implied by this general statement. The intermediate material lying say between 1.5 and 2.0 specific gravity, and consisting either of bone coal or particles of intermingled coal and shale, may make impossible an absolute separation into clean coal and refuse. Either the intermediate material will appear as a middling product or a two-group separation will be made, the so-called clean coal containing the purer bone or interstratified coal and slate, and the refuse carrying the remainder. Some of the clay may disintegrate and go into suspension making separation impossible. The shape of the particles of impurities will have a bearing on washability because specific gravity alone is not the only basis of the cleaning process, for the relative rate of settling in water depends on the shape as well as the gravity of the particles. It is evident that a flat piece of slate or a flake of pyrite, calcite, or gypsum might, in spite of its greater gravity, behave in the same way as a cube of coal.

In spite of these factors that tend to prevent a strictly specific gravity separation of coal and refuse in a commercial process the fact remains that a careful specific gravity analysis gives an excellent guide to the results that may be attained commercially. Granted perfect sampling, a specific gravity analysis shows the minimum percentages of ash and sulphur that are possible. With such an analysis and with a knowledge of the character of the coal and of the details of a given cleaning process close estimates may be made of the ash and sulphur that may be expected in washed coal. These percentages are often surprisingly close to those indicated by the specific gravity analysis.

6. *Coal Washing Processes.*—More than a century ago the practice of coal washing began in Europe, and for centuries prior to that use had been made of water and specific gravity differences in minerals to concentrate ores. It was quite natural for the term "washing" to be applied to this process of beneficiating coal, and despite the fact that air rather than water is now used in some processes, no better word than "washing" has been found. It indicates the cleaning of coal, or the removal of impurities by means other than hand-picking or the use of mechanical methods such as the spiral separator.

Such separations may be made with water as a medium, with air, or with a water-sand mixture. Upon the specific gravities of the particles of material to be treated depends in the main the working of such processes. They may be classified as:

(a) Water Processes
- Troughs or Launders
- Jigs
- Classifiers
- Tables
- Specific gravity { Sand-water mixtures / Heavy solutions

(b) Dry Processes
- Tables

Other processes in which specific gravity is not the important factor are:
- Oil "amalgam" (Trent process)
- Froth flotation

There are other processes for cleaning coal that have been tried, either on a laboratory or a commercial scale, but any coal washing process in commercial use today may be classed under one of these heads.

There is no coal-cleaning process that may be regarded as the "best" process for all coals. The characteristics of the coal and impurities and the comparative features of the various coal washing processes must be studied side by side from the standpoint of both engineering and economics before even a tentative selection of process can be made.

So much interest has been shown in coal washing during the past ten years and so rapid have been the changes in the art that technical literature contains a wealth of descriptive material and performance data. This is particularly true of air cleaning processes, the sand flotation process and the Rheolaveur process. Some recent books* also furnish valuable information, not only on processes but on the washability problem in general. Those who desire detailed information on the various coal washing processes are referred to these books, to the transactions of several of the mining institutes, and to the technical press.

III. Washability Tests

A consideration of coal preparation as presented in Chapter II suggests a basis for drawing up a plan for testing the washability of coals. It should be quite clear that such a plan must include:

*Louis, Henry, "The Preparation of Coal for the Market"
Chapman and Mott, "The Cleaning of Coal"
Minikin, R. C. R., "Modern Coal Washing Practice"
Prochaska, Ernst, "Coal Washing"

(a) The study of the coal in the mine together with careful mine sampling
(b) Tipple sampling that will give a true sample of the coal as brought from the mine
(c) A study of the specific gravity characteristics of the coal by float-and-sink tests
(d) Chemical analysis of all products, particularly for ash and sulphur
(e) An interpretation of the data secured.

7. *Mine Examination.*—At each mine a careful study was made of the coal bed and the impurities associated with it, including the roof and the floor. For sampling, from two to four locations were selected in widely separated parts of the mine and especial care was given to the study of these coal faces. At each location a columnar section of the bed was made, giving the exact location of the various bands of impurities. The method of mining was also observed, and attention given to the effects of undercutting, blasting, and loading, particularly with respect to the impurities added to the coal from the roof and floor.

In taking face samples the standard method* of the United States Bureau of Mines was followed with one slight modification. In brief, the standard method calls for a straightening and cleaning of the face and then the cutting of a channel sample from roof to floor, the size of the channel being about 12 square inches, giving a sample of about six pounds per foot of bed thickness; bands of impurities more than ⅜ inch in thickness or lenses or concretions of pyrite or other impurities more than 2 inches in diameter and ½ inch thick, may be excluded from the sample if, in the judgment of the sampler, they are excluded by the miner when he loads the coal.

In planning the methods to be followed in this investigation, it was decided that *nothing* should be excluded from the channel sample. With the rapid increase in the application of mechanical methods of loading, where the machine loads all the material that is blasted down, and where it is seldom possible to remove any impurities at the working face, it was believed that the information given by a complete channel sample would be more valuable than that given by the standard method. Accordingly a channel six inches wide and two inches deep was cut from roof to floor, care being taken to keep the size of the channel uniform, and every particle was included in the sample. This sample was then crushed to about ⅛ inch in a portable coffee-

*"The Sampling of Coal in the Mine," U. S. Bureau of Mines Technical Paper No. 1.

mill-type crusher, riffled down to three or four pounds, and sealed in a sample can for shipment to the laboratory.

At each location where a complete channel sample was taken "increment samples" were secured also, in order to make a better study of the distribution of the impurities in the coal bed. These "increment samples" were really separate channel samples of each band of impurity and of the various benches of the coal. These benches were either natural benches defined by free partings, or benches chosen by the appearance of the coal and impurities or by the assignment of an arbitrary measurement. As a rule each increment sample was taken by deepening the rectangular cross-section formed by cutting the complete channel sample.

Mine samples are designated in this report by Roman numerals (I, II, etc.) denoting the exact location in the mine as shown by the field notes. The suffix a indicates a complete channel sample. The suffix b denotes an increment sample and the Arabic numeral following it shows the location of the increment in the section of the bed. These details are shown clearly in the columnar sections for each mine, Figs. 3, 6, 8, 11, 12, 14, and 16.

8. *Tipple Samples.*—The accuracy of a study of the washability of a coal is dependent largely on the care and thoroughness expended in taking the sample for analysis.

There is considerable variation in the form, size, and quantity of impurities found in any coal bed in Illinois. This variation is particularly pronounced when considering impurities of the same bed but at widely separated areas. To a lesser extent this is even true of the coal in a single mine. The coal from one section of a mine may be very clean with few extraneous impurities, while that from another section may have a considerable amount of slate, bone, and pyrite associated with it. This variation in the amount of impurities in different sections of the mine is reflected in the tipple samples if not taken properly. During certain periods of the day trips may be coming from some sections of the mine more frequently than from others, causing a variation in the amount of impurities. This change can also be reflected in day-to-day output, for one day's loading may be better than the next. The coal that is produced a month or a year from a certain date may be different from that of the given date.

In order to have each sample as representative of the coal bed as possible, the mines were sampled over a period of at least one day's operation, and preferably two or three days were consumed in

taking the tipple samples. Such a procedure should give a reasonably representative sample of the coal produced in the particular locality in which the mine sampled is located. Furthermore, the results of the washability analyses of this sample should be fairly indicative of the ease or difficulty of removing the impurities from coal from a considerable area of this coal bed.

The size of sample to be taken is dependent on the size of the coal and size of impurities in the coal. Obviously it is much easier to sample accurately run-of-mine coal with impurities not greater than one inch in diameter than to sample run-of-mine coal with impurities as much as four inches in diameter. Chapman and Mott* calculated the effect of an excluded or included extra piece of impurity in a hundred-pound sample of coal. The authors made a similar calculation assuming that the average ash of the coal was 8 per cent and of the shale impurity 80 per cent. The specific gravity of the coal was assumed to be 1.3 and of the shale 2.6.

Size of assumed cubes, in.	Weight of coal, lb.	Weight of shale, lb.	Variation in Ash per cent
4	3	6	4.32
3	1.25	2.50	1.80
2	0.37	0.74	0.53
1	0.0046	0.0092	0.0067

It is to be noted that for sizes less than two inches, the exclusion or inclusion of an extra piece of impurity of that size does not influence the percentage error very greatly. However, the sizes above two inches are considerably affected. For example, the ash percentage of the four-inch size could be raised to $8.0 + 4.32 = 12.32$ per cent by the inclusion of an extra four-inch piece of shale in a hundred-pound sample.

A study of the theory of probability as applied to coal sampling is revealing and indicates that for average conditions a sample of at least 2000 particles should be taken to keep the probable error within $\pm$ 0.4 per cent. This agrees with tests made by Blythe and O'Shea,† who used colored counters and came to the conclusion that at least 2000 particles should be used to keep the probable error $\pm$ 0.5 per cent. Therefore, on this basis, the following samples should be taken for the sizes listed if the size of cube be taken as the diameter of the smaller round hole screen.‡

*Chapman and Mott, "The Cleaning of Coal," p. 578.

†Trans. Inst. Min. Eng., Vol. 57, p. 261, 1919.

‡With a screen ratio of 2, the diameter of the smaller hole is about the same as the edge of the cube that will pass a round hole whose diameter is the mean of the two screen hole diameters.

Screen Size, in.	Weight of Sample, lb.
6 × 3	2500
3 × 1½	312
1½ × ¾	40
¾ × ⅜	5

These calculations are based on theoretical cubes and probably give larger quantities than would be needed, for the impurities are usually more tabular than cubical. Any error is on the side of safety, and in the absence of any reasons for modifying the size of sample, these figures might well be considered as giving the minimum weight of sample that should be taken. The main value of the table is that it emphasizes the importance of taking large samples of the larger sizes of coal.

For several reasons the quantities taken of the larger sizes were less than these values. Chief among these reasons was the belief that the additional cost of collecting the larger samples would not result in any marked gain in accuracy because of the very limited amount of large pieces of free impurities in the coal. The main purpose of the investigation was to determine the quality and yield of coal that might result from washing the raw coal. Variations due to sampling would have little effect on the quality of the washed coal, and, while the yield would be directly affected by such variations, yet when referred to the run-of-mine basis the effect would not be so marked.

The following general schedule was used in obtaining tipple samples, the minimum amounts being taken for relatively clean coals and the maximum for dirty coals.

Size	Minimum Sample, lb.	Maximum Sample, lb.
6-in. lump	2000	
6 × 3 in.	500	750
3 × 1½ in.	250	300
1½ × ¾ in.	50	100
¾ × ⅜ in.	25	75
⅜ × 0 in.	25	
Run-of-Mine	3000	

The final samples for sizes of 1½ inch and less were obtained by quartering down the original samples.

During the field work a careful watch was kept on the character of the tipple products to see whether the actual conditions checked up with the assumptions on which the schedule was based. At every mine it was felt that the samples secured represented a good average for the period (a day or more) during which the samples were taken. After all tests had been made and the analyses completed, it was found that the regularity of the general results confirmed this feeling.

At most of the mines it was either necessary or deemed best to take the tipple samples from run-of-mine rather than sized coal. These samples were then sized at the laboratory previous to making the washability tests. It will be noted from the results of the screen analyses of the run-of-mine samples that in practically every case the largest sizes (6×3, $3 \times 1\frac{1}{2}$) amounted to from 20 to 30 per cent of the total sample, thus giving at least 500 pounds of each of these sizes for testing purposes. Thus a run-of-mine sample of the amount recommended, upon being screened in the laboratory, gave enough of the various sizes by weights to more than satisfy the minimum requirements as outlined.

Coal is subject to breakage from the time it is shot down in the mine until it reaches the railroad cars. Loading underground, transportation, hoisting, and screening constitute the chief means of breakage. There is not much variation in the way a coal is handled until it reaches the tipple. It is important from a washability standpoint to take the sample before it has a chance to be further broken up in passing through the tipple, that is, it is of importance to know the sizes being made as well as the amount of impurities in determining the washability characteristics of a coal. For this reason samples were generally taken from the feeder just before the coal entered the main shaker screen. Consequently, practically all samples were representative of the coal as it came to the tipple and not broken up or cleaned other than is normally done in mining, haulage, and hoisting operations.

The difficulty of sampling large sizes of coal has been mentioned. The difficulties encountered in attempting to sample a large stream of run-of-mine coal from a mine producing a large tonnage are also apparent. Grab sampling is inaccurate both as to size distribution and impurity distribution due to segregation of sizes and impurities at certain definite points in a stream of moving coal. The best method is to cut a stream of moving coal at stated intervals removing a complete section of the stream at each sampling period. The sampling should continue through at least one day's operation. It is rather easy to cut a section out of a stream of moving coal with large scoop shovels, provided the size of the coal is not greater than about 2 inches. It is much more difficult to cut a stream of the larger sizes. This can be accomplished by two men using a sampling cloth or canvas, stationed one on each side of the feeder, chute or stream of coal. All samples after being taken were carefully sacked in good strong bags,

marked "Handle with Care" and shipped to the laboratory where facilities were such that they could be screened and tested under ideal conditions.

9. *Chemical Analysis.*—To secure samples of raw coal or float-and-sink fractions for chemical analysis, a riffle sampler was used exclusively in order to avoid any errors that might be introduced by coning and quartering. The final samples were ground in a horizontal-disc pulverizer to pass a 60-mesh sieve, placed in rubber-stoppered sample bottles, and thoroughly mixed on a mixing wheel.

Standard methods of coal analysis, or modifications thereof, were used in this work. Moisture was determined by heating for one hour at 105 deg. C. in an electric oven having thermostatic control. Volatile matter was run by heating a 1-gram sample in a 10-cc. platinum crucible with a capsule cover for exactly 7 minutes at 950 deg. C. in a Fieldner furnace with a control rheostat; the temperature was determined by a standardized thermocouple. Ash was determined by ignition in an electric muffle furnace.

For total sulphur, the sodium peroxide fusion method of Parr was followed, the sulphur being weighed as barium sulphate. Pyritic sulphur and "sulphate" sulphur were determined by the methods of Parr and Powell,* and organic sulphur by difference.

Since the calorific values of the raw and the washed coal were not of as much interest as the ash and sulphur content, it was decided not to determine the calorific values in the calorimeter but to calculate them from the known unit coal values determined for coals of these localities in other investigations. Parr has shown† how uniform is the unit coal value for a given coal bed over an entire county and many unit values for Illinois coal beds have been published‡ by the State Geological Survey. Some of the mine samples were tested in the oxygen bomb calorimeter by the United States Bureau of Mines, and in these cases unit coal values were calculated from such determinations. Unless special notation is made in the tables, all calorific values have been calculated from reliable unit coal values. It is believed that these calculated calorific values are sufficiently exact for any use to which the results of this investigation may be put.

*"A Study of the Forms in Which Sulphur Occurs in Coal," Univ. of Ill. Eng. Exp. Sta. Bul. 111, 1919. "The Analysis of Sulphur Forms in Coal," U. S. Bur. Mines Technical Paper 254, 1921.

†"Purchase and Sale of Illinois Coal on Specifications," Ill. State Geological Survey Bul. 29, 1914.

‡"Analyses of Illinois Coals," by G. W. Hawley. Ill. State Geological Survey, Coöp. Mines Investig. Bul. 27, 1923.

Determinations of the fusibility of ash were made according to the standard method of the American Society for Testing Materials. The ash of coal is classified in three groups according to its fusibility:

Class 1, refractory ashes, softening above 2600 deg. F.

Class 2, ashes of medium fusibility, softening between 2200 and 2600 deg. F.

Class 3, easily fusible ashes, softening below 2200 deg. F.

10. *Float-and-Sink Tests.*—The prime purpose of any plan of preparation or washing of coal is to improve its quality by lowering the amount of ash or sulphur or both. Any such improvement results from a separation of the good coal from its accompanying free impurities. Any study of the washability of a coal must therefore be based on a similar separation, but a separation that will result in several fractions so that there will be opportunity to judge of the quality of the resultant products in order to ascertain the point at which the best separation can be made.

The basis of any commercial coal washing process is the difference in specific gravity between the coal and the impurities, but such variables as shape of particles, rate of feed, speed of mechanism, etc., necessitate a rather long period of adjustment of machinery before the best and most uniform results can be obtained. It is the effect of such variables that makes it inadvisable to study the washability of a coal by running brief tests on small-scale machines. It is much more advisable to use a test method in which all these variables are eliminated and the separation is based solely on differences in specific gravity. This is called the float-and-sink method of testing.* It utilizes heavy-gravity solutions in which the separations can be made at several different specific gravities and the products removed for analysis. The proper arrangement and interpretation of these results will show:

(1) Amount and distribution of impurities, particularly ash and sulphur, in the different specific gravity fractions.

(2) The degree that a coal can be improved by cleaning methods with amount and kind of products to be expected.

(3) A suggestion as to the best type of cleaning plant to use on the coal under investigation.

(4) An indication as to whether the coal will be easy or hard to clean.

*Discussions of this and other methods may be found in considerable detail in: Chapman and Mott, "The Cleaning of Coal"; Henry Louis, "The Preparation of Coal for the Market"; "Coal Washing Investigations," U. S. Bur. Mines Bul. 300, 1929.

(5) The minimum percentages of ash and sulphur that can be obtained, with recoveries. Inherent ash and sulphur can be determined for the purest coal of any particular size.
(6) The nature and amount of the impurities in any size.
(7) The occurrence of impurities as to whether free or interstratified in the different fractions. This will tend to show whether middlings should be recrushed and further treated.
(8) The efficiency of existing coal cleaning plants may be determined.

Sizes above 6 inches cannot be treated with any degree of satisfaction by float-and-sink methods. Since such sizes are generally handpicked in cleaning plants, it is obviously unnecessary to try and treat such large sizes by any other method than handpicking. However, the products from handpicking, if their appearance justify it, should be crushed and treated by the float-and-sink process in order to determine what yield of good coal could be expected by crushing these products to a finer size.

Illinois coal above 3 inches in size can usually be picked by hand in competition with mechanical cleaning plants. Sizes below 3 inches must be cleaned mechanically if any satisfactory reduction in ash is to be expected. Although sizes above 1 inch are generally not investigated by the float-and-sink method, yet cleaning plants are treating larger sizes than formerly, some plants even treating sizes as coarse as 6 inches. In order to get as clear a picture of a coal as possible, it was therefore decided to attempt testing of all sizes below six inches. Apparatus, which is described later, was therefore designed which enabled these larger sizes and correspondingly large samples to be tested with practically the same ease and dispatch that the smaller sizes normally are tested. In general then, in order to get a complete picture of a coal, the following sizes were tested in the laboratory:

By Handpicking—6-in. lump

By Float-and-Sink Test—	By Float-and-Sink Test—
6 × 3-in.	$\frac{3}{16}$ × 10 mesh
3 × 1½-in.	10 × 20 mesh
1½ × ¾-in.	20 × 48 mesh
¾ × ⅜-in.	48 × 0 mesh
⅜ × $\frac{3}{16}$-in.	

As a rule the minus 48-mesh coal was tested as one size, but in one or two instances it was divided into three sizes for testing—48 x 100, 100 x 200, and minus 200 mesh. All screens from 6-in. to

$\frac{3}{16}$-in. inclusive were round hole punched plate screens. Standard Tyler sieves were used for 10 mesh and finer.

The sizes selected for testing, or their combinations, are the sizes generally made at Illinois mines, and the test results can therefore be applied directly to commercial practice.

Two general types of heavy-gravity liquids are available: aqueous solutions and organic liquids. Calcium chloride and zinc chloride solutions are examples of the former that are generally used. Carbon tetrachloride, benzol, and bromoform are examples of the second type.

Zinc chloride has a wider range of specific gravities when mixed with water than has calcium chloride, and hence has the widest application in float-and-sink testing. Zinc chloride is cheap, and solutions of this salt and water will last for a long time if the solution is filtered from time to time to remove fine particles of shale, pyrite, and coal. Care must be exercised in washing this solution from the float-and-sink fractions since the solution tends to coat the coal and if not washed off properly may cause erroneous results. Solutions of this salt are thick and viscous and do not wet fine coal readily. It is very difficult, however, to wash the solution from fine coal. Therefore, the use of zinc chloride is not recommended for sizes finer than $\frac{3}{8}$ in.

Carbon tetrachloride mixed with benzol or bromoform makes an ideal solution for treating the finer sizes of coal. At 25 deg C. the specific gravity of carbon tetrachloride is 1.584, that of benzol 0.88, and that of bromoform 2.88.

Almost any range of specific gravities can be secured with mixtures of these solutions. The volatility of carbon tetrachloride and benzol is practically the same, so that there is very little change in specific gravity due to differential volatilization when mixtures of these two are being used. When treating dust or very fine coal, special precautions are necessary and the separation should be made in an air-tight apparatus.*

A sufficient number of solutions of different specific gravities should be used so that information can be obtained covering the range from the purest coal to the cleanest refuse. Many investigators consider three or four solutions of specific gravities of the order 1.40, 1.60, and 1.75 to be sufficient. The greatest objection to this is that there are not enough fractions to give an accurate picture of the coal. In this work it was decided to use solutions having specific gravities 1.30, 1.35, 1.40, 1.50, 1.60, and 1.70.

*"The Float-and-Sink Testing of Fine Size Coal," Univ. of Wash. Eng. Exp. Sta. Bul. 46.

The coal that floated on a solution of 1.30 specific gravity was further tested in a solution whose specific gravity was varied in order to determine the quality of the purest coal. This same procedure can be followed out with the 1.70 sink in order to determine the character of the heaviest impurity, but is not so necessary unless pyrite recovery is an item. It is also more difficult of accomplishment than determining the character of the purest coal. The specific gravity of a large part of the coal substance of most bituminous coals lies between 1.30 and 1.40. Therefore, the greatest percentage of material floats at gravities of 1.30 and 1.40. In order to eliminate as far as possible the danger of entrapment of particles in these large fractions, an intermediate solution of 1.35 specific gravity was used between these two.

Coals from the Eastern interior field have a high bed moisture content, in many cases as high as 16 per cent. These coals lose moisture rapidly after being mined if exposed to air. Under conditions that generally prevail in most laboratories this moisture content will drop to one-half or one-quarter of what it was when in the "as mined" condition. There is also some change in specific gravity as the moisture content changes. Nebel* found that there may be as much as 0.10 difference in apparent specific gravity between coal in the saturated condition and coal in the air-dry condition. Thus it is possible that a coal that would float in a solution of 1.40 specific gravity in the dry state might sink when in the saturated condition. Since any coal washing process at the mine takes coal *direct* from the mine, it is desirable that laboratory tests should be made on samples in a fresh-mined condition; therefore, separations should be made on samples that have been restored to this condition by soaking in water. If the coal has as an impurity shale, which easily goes into suspension in water, this may not be possible. Some of the error due to this may be obviated by immersing the coal in the heaviest solution first, removing the heavy refuse particles first, and thus avoiding to some extent the contamination of the coal particles by suspensoids.

The larger sizes can be tested in zinc chloride after being water soaked and then surface dried. The finer sizes are not easily freed from zinc chloride by rinsing so that it is preferable to air dry them and then test in organic liquids. Tests at the University of Washington have shown† that the rapid absorption of organic liquids by air-dried coal quickly brings the coal to the same apparent specific gravity

*"Specific Gravity Studies of Illinois Coal," Univ. of Ill., Eng. Exp. Sta. Bul. 89.
†"The Float-and-Sink Testing of Fine Size Coal," Univ. of Wash. Eng. Exp. Sta. Bul. 46.

that it had when in the freshly-mined condition. Similar tests at the University of Illinois have shown that the same results are secured with the Illinois coals tested.

After the coal has been separated into the various fractions, it should be air dried, analyzed, and all results calculated to a moisture-free basis. The results obtained by the methods just given are directly comparable since everything is on a moisture-free basis.

All washability curves have been drawn for moisture-free values, but the percentage of moisture in the freshly-mined coal is given in the discussion under washability curves for each coal so that the percentages of ash and sulphur may be calculated back if desired.

While the tabulations for washed coal yields have been made in every case on the assumption that the washed coal contained the same moisture percentage as the freshly-mined coal, yet because the curves are on a moisture-free basis it becomes an easy matter to calculate the analyses for any assumption of moisture that may be dictated by the process used or by the experience of the engineer.

11. *Development of Washability Curves.*—The use of washability curves was first suggested by Charvet.* R. A. Henry took up the idea in England in 1905 and made extensive use of it. He is credited with their development and such curves are called Henry curves or ash characteristic curves as well as washability curves.

The Henry method consisted in jigging the coal under investigation in an iron tube four inches in diameter and about two feet long. The bottom of the tube was fitted with a fine wire screen and handles were attached to the top. Under the action of jigging in a tub of water, the heavy refuse collected on the screen at the bottom and the lightest coal collected at the top with intermediate gravity material in between. The bottom screen of the Henry tube is fitted to act as a piston so that after stratification is complete the coal can be pushed out and successive layers taken off for weighing and analysis.

In the Henry tube the coal is not stratified strictly according to its specific gravity. The length of jigging stroke, the number of strokes, and the rapidity of strokes are all variables. If a quick, short stroke is used, then the particles will follow more nearly the laws of hindered settling. Any great variation in size of particles will tend to cause erroneous results in the Henry tube since a small particle of refuse will tend to stratify out with a larger particle of coal. These disad-

*Bul. Soc. de l'Ind. Min., 2, 1903.

TABLE 1

HENRY TUBE DATA AND CALCULATIONS

1	2	3	4	5	6	7	8	9	10	11
Layer Number	Weight Percentage of Layers	Ash Percentage of Layers	Cumulative Weight Percentage to Mid-point of Layers*	Product (Col. 2 × Col. 3)	Cumulative Weight Percentage to Bottom of Layers (1 to 10)	Cumulative Products (1 to 10)	Cumulative Ash Percentage Coal Recovery (Col. 7 ÷ Col. 6)	Cumulative Weight Percentage (10 to 1)	Cumulative Products (10 to 1)	Cumulative Ash Percentage Refuse Reject (Col. 10 ÷ Col. 9)
1	8.6	3.6	4.3	31.0	8.6	31.0	3.6	100.0	1485	14.9
2	10.2	4.0	13.7	40.7	18.8	71.7	3.8	91.4	1454	15.9
3	10.6	5.0	24.1	53.0	29.4	124.7	4.2	81.2	1413	17.3
4	9.4	6.0	34.1	56.4	38.8	181.1	4.7	70.6	1360	19.3
5	11.0	6.9	44.3	75.9	49.8	257.0	5.2	61.2	1304	21.3
6	10.2	8.5	54.9	86.6	60.0	343.6	5.7	50.2	1228	24.4
7	9.4	9.0	64.7	84.6	69.4	428.2	6.2	40.0	1142	28.5
8	10.0	11.2	74.4	112.0	79.4	540.2	6.8	30.6	1057	34.5
9	10.4	12.5	84.6	130.0	89.8	670.2	7.5	20.6	945	45.8
10	10.2	80.2	94.9	815.0	100.0	1485.2	14.9	10.2	815	80.0

Ash Distribution Curve (D) = Column 4 as ordinates plotted against Column 3 as abscissas.
Coal Recovery Curve (A) = Column 6 as ordinates plotted against Column 8 as abscissas.
Refuse Reject Curve (R) = Column 9 as ordinates plotted against Column 11 as abscissas.
*Each number in this column is secured by adding half of the corresponding number in Column 2 to the sum of the preceding numbers in Column 2.

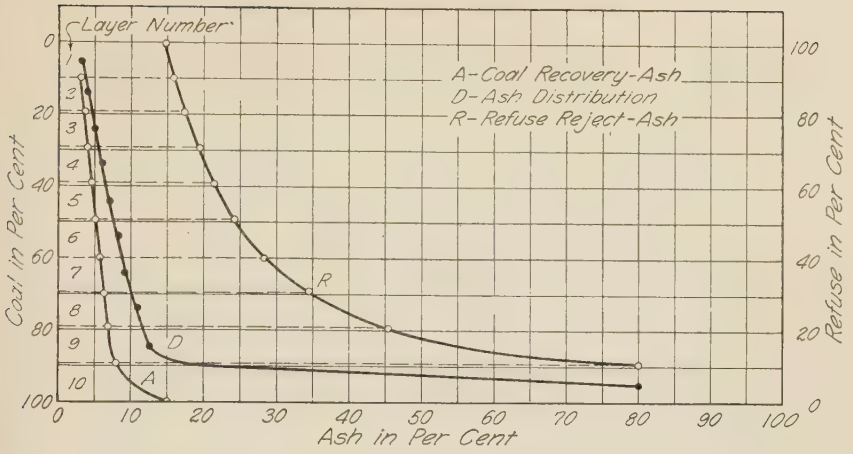

Fig. 1. Henry Curves

vantages of the Henry tube are eliminated in the float-and-sink method, since it is a method depending entirely on specific gravity.

The layers of the coal in the Henry tube correspond to the fractions as obtained by immersing coal in a series of increasingly heavy liquids. The light coal at the top of the Henry tube is comparable to the light float coal obtained from immersing the coal in the liquid of lowest specific gravity, and the refuse in the bottom of the tube is similar to the sink material obtained by immersing the coal in a liquid of relatively high specific gravity.

The data in Table 1 were obtained from the operation of the Henry tube. The ash analysis of the layers is assumed to represent the ash content of that part of the coal just at the mid-point of each layer. Therefore a curve that is plotted using the mid-point of each successive layer as an ordinate and the corresponding ash content as abscissa, shows the characteristics of the entire sample from lightest coal to heaviest refuse. This is called the Ash Distribution curve (see Fig. 1).

The coal under consideration has a very small amount of middling but considerable high-ash impurity. Each layer is considered as an increment of the whole. If then a weighted average is made of the weight percentage of each successive layer and its ash percentage, the average ash percentage of the entire sample may be determined. In this case it is 14.9 per cent.

Similarly the ash percentage of any portion of the coal made up of any number of layers may be calculated. The Coal Recovery curve

Table 2

Typical Calculations for Curves

Mine E, Tipple Sample P, Size No. ¾ x ⅜ inch

1	2	3	4	5	6	7	8	9	10	11	12
					Cumulative Float			Cumulative Sink			
Specific Gravity	Weight lb.	Weight per cent	Ash per cent	Products (Col. 3 × Col. 4)	Weight per cent	Products	Ash per cent (Col. 7 ÷ Col. 6)	Weight per cent	Products	Ash per cent (Col. 10 ÷ Col. 9)	Ordinate for Curve D*
1.30 Float	116.60	61.6	8.23	507.0	61.6	507	8.23	100.0	1645	16.45	30.80
1.30–1.35 Float	35.71	18.9	10.75	200.0	80.5	707	8.79	38.4	1138	29.63	71.05
1.35–1.40 Float	6.92	3.7	17.80	65.8	84.2	773	9.18	19.5	936.6	48.07	82.35
1.40–1.50 Float	5.86	3.1	24.69	77.4	87.3	850	9.74	15.8	871.8	55.15	85.75
1.50–1.60 Float	2.76	1.5	31.13	46.7	88.8	897	10.11	12.7	794.4	62.55	88.05
1.60–1.70 Float	2.29	1.2	37.75	45.3	90.0	942	10.46	11.2	747.7	66.80	89.40
1.70 Sink	18.87	10.0	70.24	702.4	100.0	1645	16.45	10.0	702.4	70.24	95.00
					Cumulative Float			Cumulative Sink			
Specific Gravity	Weight lb.	Weight per cent	Sulphur per cent	Products (Col. 3 × Col. 4)	Weight per cent	Products	Sulphur per cent (Col. 7 ÷ Col. 6)	Weight per cent	Products	Sulphur per cent (Col. 10 ÷ Col. 9)	Ordinate for Curve D*
1.30 Float	116.60	61.6	3.77	232.2	61.6	232.2	3.77	100.0	511.1	5.11	30.80
1.30–1.35 Float	35.71	18.9	4.52	85.4	80.5	317.6	3.95	38.4	278.9	7.26	71.05
1.35–1.40 Float	6.92	3.7	5.86	21.7	84.2	339.3	4.03	19.5	193.5	9.92	82.35
1.40–1.50 Float	5.86	3.1	7.06	21.9	87.3	361.2	4.14	15.8	171.8	10.87	85.75
1.50–1.60 Float	2.76	1.5	8.35	12.5	88.8	373.7	4.21	12.7	149.9	11.79	88.05
1.60–1.70 Float	2.29	1.2	9.72	11.7	90.0	385.4	4.28	11.2	137.4	12.26	89.40
1.70 Sink	18.87	10.0	12.57	125.7	100.0	511.1	5.11	10.0	125.7	12.57	95.00

*Each number in this column is secured by adding half of the corresponding number in Column 3 to the sum of the preceding numbers in Column 3.

is so calculated, starting at the top of the layers and working downward until all of the layers have been included to give the average for the sample. The data for the Refuse Reject curve can be calculated in a similar manner. However, in order to determine the ash of any successive cuts of refuse as determined by the layers, calculations must begin at the bottom, in this case with Layer No. 10, and progress up until Layer No. 1 is included, or 100 per cent of the sample. This curve can then be plotted in the same way as the Coal Recovery curve. If the calculations are correct, the ash for 100 per cent coal recovery should check with the ash for 100 per cent refuse reject.

The calculations involved in float-and-sink analysis are exactly the same, the float-and-sink fractions corresponding to the layers as taken from the Henry tube. One additional curve is added to the three already described, the specific gravity curve. This curve is plotted by using weight percentages as ordinates and specific gravities as abscissas. It gives, therefore, the specific gravity of the solution required to effect any desired separation.

It is sometimes advantageous to know the sulphur distribution in a coal. A complete set of washability curves for sulphur can be constructed similar to those constructed for ash. The method of calculation is exactly the same.

Table 2 gives all of the laboratory data taken and the calculations made in the construction of washability curve No. 39 for Coal E, Tipple Sample P, Size ¾ x ⅜ in. The ash and sulphur percentages were calculated to a moisture-free basis before calculations were made for the curves. The table includes both ash and sulphur calculations but a complete set of sulphur curves was not made for each coal, since sulphur elimination is shown in sufficient detail by including the one curve "S," "Coal Recovery—Sulphur," with the general curves for ash removal. Column 12 in this table corresponds to Column 4 in Table 1 for the Henry tube.

12. *Interpretation of Washability Curves.*—The plotting of the data obtained in the form of washability curves provides a means of quick interpretation and is more instructive than a study of the data alone. The shape of the curves tells at a glance whether the coal is easy to clean, or whether it cannot be materially improved by cleaning processes.

Two theoretical examples are given. The first is shown by Fig. 2a. The sample analyzed 20.8 per cent ash, but the washability curve shows that the sample really consists of 80 per cent of clean coal with

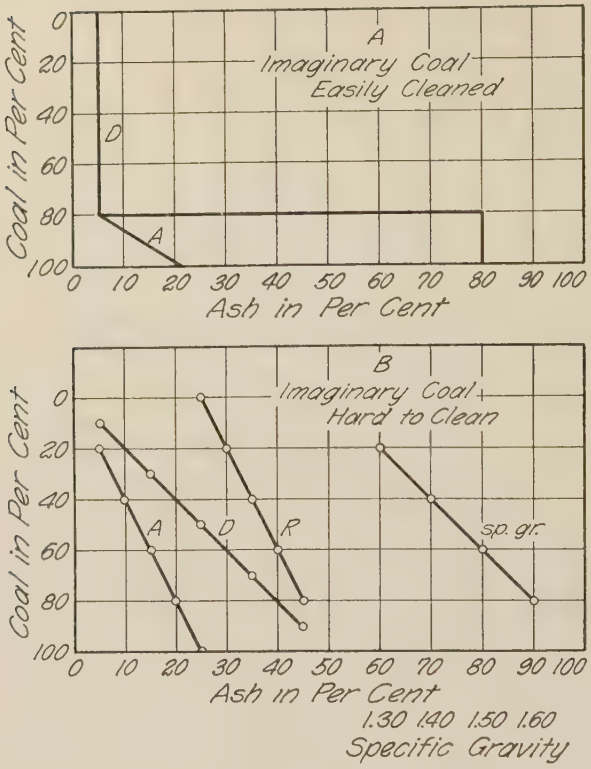

Fig. 2. Imaginary Coal Easily Cleaned and Hard to Clean

5 per cent ash and 20 per cent of refuse with 80 per cent ash. Curves D and A are coincident down to the 80 per cent recovery. While it is very unlikely that such a coal would ever be found, yet the assumed data illustrate a coal that would be easy to clean, for there is a sharp line of demarcation between coal and refuse because of the break in the ash content of the two products and because there is no intermediate product.

The second coal, represented by the curves in Fig. 2b, was assumed to have the following washability analysis:

Weight, per cent	Ash, per cent
20	5.0
20	15.0
20	25.0
20	35.0
20	45.0

The average ash for the sample is 25 per cent, only a little more than that for the preceding sample. In this case, however, the ash distribution curve D is a uniform diagonal line as contrasted with the vertical and horizontal lines for the other coal. It is quite evident, therefore, that this second coal is not made up of clean coal and refuse and would not show a sharp separation when jigged in a Henry tube, but rather a gradually increasing ash percentage from top to bottom. Hence no improvement of the coal is possible without throwing away a large amount of reject. For example, Curve A shows that to obtain a coal with 10 per cent ash the yield would be only 40 per cent, while the reject curve shows that the 60 per cent thrown away would contain but 35 per cent of ash.

It is not likely that any coals will be found in nature representing these two extremes. However, by comparing actual ash distribution curves with these extreme assumptions to see whether they approach the one example or the other, very definite information can be had as to the ease or difficulty of cleaning the particular coal under examination. An example of an average coal would be that of washability curve No. 39, Mine E, for the ¾ x ⅜ in. size. Washability curve No. 17, Mine B, for the same size is an example of a coal that is impossible to improve very much by any cleaning process unless a large amount of the coal is thrown away.

13. *Laboratory Procedure.*—The samples, when received at the laboratory, were sized as soon as possible. The treatment of each size was the same for all coals.

Sizes above ⅜ inch were treated in solutions of zinc chloride. They were first water-soaked for at least 12 hours. Just before being immersed in the zinc chloride solution, the samples were surface dried by spreading out on a draining table. As soon as the samples were surface dried, they were immersed in the solution of lowest specific gravity, the coal being stirred thoroughly, and then the float removed to the draining table where the zinc chloride was washed off with a water spray. After surface drying the fraction was weighed wet, then air dried and weighed. The fraction was then crushed quickly and sampled for chemical analysis. The treatment of succeeding float-and-sink fractions was identical with the one described.

In addition to this standardized method of treating the various fractions, all or part of the first fraction was placed in a liquid of very low specific gravity and the specific gravity of the solution gradually raised until a few particles of coal floated. These particles were

taken in order to determine the specific gravity, ash, and sulphur percentage of the purest coal obtainable for any given size.

In order to facilitate handling the large samples of the coarse sizes, a row of 18 x 24-in. galvanized iron cans was used for the solutions. The cans were placed directly under an overhead trolley from which a chain block was suspended. To the chain block was attached a cylindrical wire screen that fitted snugly into the cans.

The method of operation consisted in placing the screen in a can containing the desired specific gravity solution. The coal was then placed in the solution, thoroughly stirred and then the float removed. After the float was removed the cylindrical screen containing the sink material was raised high enough above the liquid to permit the solution to drain off thoroughly. It was then moved along the trolley to a position above the next can and immersed in the liquid. By jigging the can up and down with the chain block or by a pole thrust through the handles of the screen, a complete freeing of entrapped particles could be effected very easily. This proved a very rapid method and on a smaller scale was adopted for sizes from ⅜ inch to 48 mesh.

In treating these finer sizes heavy organic liquids were used. The coal was thoroughly dried before being immersed in the liquids. Battery jars were used, with a 100-mesh screen to remove the sink and transfer the sample from one jar to the next. Since small samples can be used in the smaller sizes this provided a very quick and effective means of treatment.

Sizes below 48 mesh should be treated in air-tight containers, for, due to the length of time the sample must remain in the container before there is a complete separation of sink and float, there would be a rapid evaporation of the exposed liquid. Two types of apparatus were used, that of Bird and Messmore* and one made up in the laboratory of two glass tubes, each 4 inches in diameter and 18 inches long. These tubes were mounted on a stand and were connected together with a rubber tube which could be closed by means of a clamp. Both tubes had sloping bottoms so that sink material would not lodge where the tubes were narrowed down for the rubber connections. The connected tubes were filled with the organic liquid, the coal sample added slowly with frequent stirring and then the upper tube was corked. The sink material was collected in the lower tube and the float in the upper tube. By means of the clamp on the connecting rubber tube, the liquid and sink material in the bottom could be drained off and, if necessary, the glass tube removed and washed out. The float coal could

*"The Float-and-Sink Testing of Fine Size Coal," Univ. of Wash. Eng. Exp. Sta. Bul. 46.

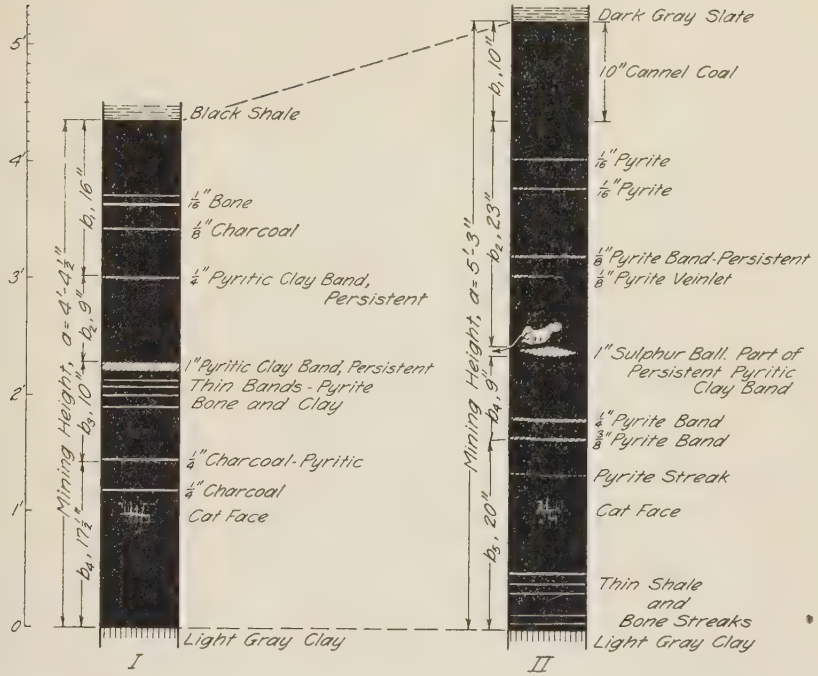

FIG. 3. FACE SECTIONS OF NO. 5 COAL, LASALLE COUNTY, MINE A

then be dropped down through the lower glass tube to a container, the upper glass tube could be removed from the stand and the float coal removed from it, or while the connection was removed from the lower glass tube the float could be removed through the bottom of the upper glass tube without removing it from the stand. This proved to be a flexible and satisfactory method of treating the very fine sizes.

All coal treated in carbon tetrachloride solutions was thoroughly dried after treatment, weighed, and then sampled for chemical analysis.

IV. DESCRIPTION OF COAL BEDS AND MINES AND DISCUSSION OF TEST RESULTS

14. *Mine A, Coal No. 5, LaSalle County.*—There are two distinct types of coal found at this mine, bituminous and cannel. The cannel coal occurs in patches overlying the bituminous part of the bed, see Fig. 3, and does not constitute more than 10 per cent of the mine output.

The cannel coal is hard and breaks with a splintery fracture into flat tabular pieces. It is not a high grade cannel coal, as can be seen from the analysis of increment sample number AIIb1 in Table 3. The percentage of volatile matter is low, and the ash and sulphur percentages are high. It appears to grade from a good cannel coal where it rests on top of the bituminous part of the bed to a bituminous shale where it joins the roof slate.

The bituminous part of the bed is made up of banded bright and dark coal layers characteristic of this type of coal. It is hard and blocky, and breaks into nearly cubical lumps. It resists breakage due to handling and stands up well under preparation methods with very little loss of the commercial sizes due to degradation.

The bed averages approximately 52 inches in thickness where the cannel coal is absent and 62 inches where it is present. Two mine samples were taken, one where the cannel coal was absent and one where it was found. In Fig. 3, face section I is typical of this bed where the cannel coal is absent, while face section II is typical of the bed where the cannel coal occurs.

Impurities

The principal impurities are bands of pyrite, shale, bone, and mineral charcoal. White flakes of calcite and gypsum are numerous in the vertical cleavage planes. That these flakes are chiefly calcite was determined from a microscopical study of the coal as well as from the sulphate sulphur analyses of the samples as shown in Table 3. Some vertical flakes of pyrite were noticed as shown by the cat-faces in Fig. 3 near the bottom of the face sections.

A pyrite or pyritic shale band near the top and one near the bottom seem to be characteristic of this bed. They vary from a streak to two inches in thickness. These thickened portions of the bands are generally massive pyrite lenses. Thin bands of mineral charcoal also widen at times to pyrite balls or lenses. The mineral charcoal found at this mine occurs chiefly in thin bands and in less quantity than at some of the other mines sampled.

The roof is a black or dark gray slaty shale which weathers fairly easily. Numerous concretionary masses are found in this top shale. Due to the system of mining used, there is very little of this top shale accidentally mixed with the coal during mining operations.

The floor is a soft clay and very uneven. Due to this uneven nature of the floor, a mining machine kerf that starts in coal on one side of the room may be in clay on the other side. There is some contami-

Table 3

Analyses of Mine Samples—Mine A

As Received

Sample Number	Moisture	V. M.	F. C.	Ash	Total Sulphur	Sulphate Sulphur	Pyritic Sulphur	Organic Sulphur	Calculated B.t.u.	Softening Temperature of Ash deg. F.
AIa	12.95	36.08	36.39	14.58	4.04	0.08	2.00	1.96	10 190	2110
AIIa	11.61	35.57	37.13	15.69	5.51	0.14	3.63	1.74	10 170	2390
AIb1	13.45	38.41	40.44	7.70	1.97	0.04	0.89	1.04	11 250	2170
AIb2	14.32	37.51	39.48	8.69	3.56	0.05	1.82	1.69	10 920	2312
AIb3	13.22	35.53	38.29	12.96	2.78	0.05	1.26	1.47	10 440	2225
AIb4	12.85	39.50	30.34	17.31	4.06	0.05	1.61	2.40	9 920	2261
AIIb1	6.47	42.00	33.94	17.59	5.56	0.10	3.40	2.06	10 280	2358
AIIb2	11.37	38.70	39.74	10.19	3.71	0.07	2.12	1.62	10 890	2477
AIIb3	2.97	23.57	12.13	61.33	41.70	0.38	40.26	1.06	3 200	2477
AIIb4	10.32	32.25	36.77	20.66	9.72	0.31	6.97	2.44	9 550	2390
AIIb5	12.95	35.06	38.63	13.36	5.52	0.16	3.35	2.01	10 330	2342

Suffix a indicates complete channel sample.
Suffix b indicates increment samples; see Fig. 3.

nation of the coal with this bottom clay which undoubtedly helps to contribute to the high ash content of the finer sizes. This clay would slime considerably in a wet coal cleaning process.

Mine Samples

The mine was sampled at two widely separated places, the extreme southern and northern parts. Practically all of the coal is produced from these two sections. A complete channel sample was taken at each place sampled as well as a set of increment samples. Figure 3 depicts graphically the face sections sampled, as well as giving the key numbers to the increment sample analyses of Table 3.

The average mine moisture of this mine is 12.3 per cent. This is two or three per cent lower than is normally expected from mines in this field. The ash and sulphur percentages are high, averaging about 15 and 4½ per cent, respectively. The top bench or benches of coal are the cleanest, as can be seen from the analyses of the bituminous increment samples. This is directly opposite to the general belief that the top sections of coal are the dirtiest. The cannel coal sample is an exception and runs rather high in ash. The calorific value of the coal as mined is approximately 10 200 B.t.u. The softening temperature of the coal ash from this coal is fairly high for Illinois coals and will fall within Class 2. As compared with other coals the ash is of medium fusibility, the temperature of fusion ranging from 2110 to 2477 deg. F.

The total sulphur is high in all samples. The organic and sulphate forms are very constant, and indicate that there would be very little variation in organic sulphur throughout a considerable area of the bed. The organic sulphur is approximately 50 per cent of the total sulphur, except where pyrite bands or veins abnormally increase the percentage of total sulphur. Since only pyritic sulphur, and that only if not too fine, can be eliminated by cleaning methods, very little reduction in the percentage of sulphur can be expected from any cleaning process, certainly not over 2 per cent.

Tipple Sample

This mine is equipped to make the following sizes: 5-in. lump, 5 x 1½-in. egg, 1½-in. screenings, 5 x $\frac{5}{32}$-in. modified egg, and $\frac{5}{32}$ x 0-in. screenings, or so-called duff coal. Generally only the 5 x $\frac{5}{32}$-in. and the $\frac{5}{32}$ x 0-in. sizes are made. When making these sizes the 5-in. lump is passed through a single roll crusher set at 5 in. and joins the screened 5 x $\frac{5}{32}$-in. coal. This crushed coal has in it a considerable amount of flat tabular pieces, especially of cannel coal, that are considerably

TABLE 4

SCREEN ANALYSIS—MINE A

Sizes	Weight per cent	Cumulative Weight per cent	Ash per cent (Moisture Free)	Sulphur per cent (Moisture Free)
Sample P (5 in. x Duff)*				
5 x 3 in.†	30.7	30.7	16.25	5.71
3 x 1½ in.	33.3	64.0	12.15	4.59
1½ x ¾ in.	16.3	80.3	13.48	4.28
¾ x ⅛ in.	12.1	92.4	14.09	5.46
⅛ x ⅛ in.	2.5	94.9	15.12	4.02
⅛ x 0 in.	5.1	100.0	22.81	4.64
Totals and averages	100.0		14.64	4.98
Sample Q (Duff)				
⅛ in. x 20 mesh	49.6	49.6	18.94	4.34
20 x 48 mesh	28.8	78.4	25.61	4.48
48 x 100 mesh	9.8	88.2	27.30	5.15
100 x 200 mesh	3.9	92.1	28.15	5.56
200 x 0 mesh	7.9	100.0	19.23	3.79
Totals and averages	100.0		22.06	4.46

*Duff is coal that passed through a $\frac{5}{32}$-in. screen at the tipple.
†Coal passed through a crusher set at 5 in. and over a 3-in. round hole screen.

larger than 5 in. This crushed 5-in. lump after joining the 5 x $\frac{5}{32}$-in. screened coal is fed to a main conveyor belt. The sample for float-and-sink analysis was taken from the feeder to this main conveyor belt by removing a section across the stream of flow every few minutes during an entire day's production. A sample of 2000 pounds of this size was taken for sizing and float-and-sink analyses. This is Sample P, and represents 98.3 per cent of the mine output. The duff ($\frac{5}{32}$ x 0-in.) coal passes from the screen to a chute and thence to slate cars in which it is taken to the refuse dump. This duff coal is very dirty, and is not considered worth saving. Nevertheless, a sample of approximately 400 pounds was taken by cutting the stream as it came from the chute to the slate cars at stated intervals. This sample is known as Sample Q, and represents only 1.7 per cent of the mine output.

Test Procedure and Washability Analyses

The coal from the two samples was sized into the sizes given in Table 4 for the two samples, P and Q. The larger sizes were subjected to float-and-sink analyses in their entirety, while the smaller

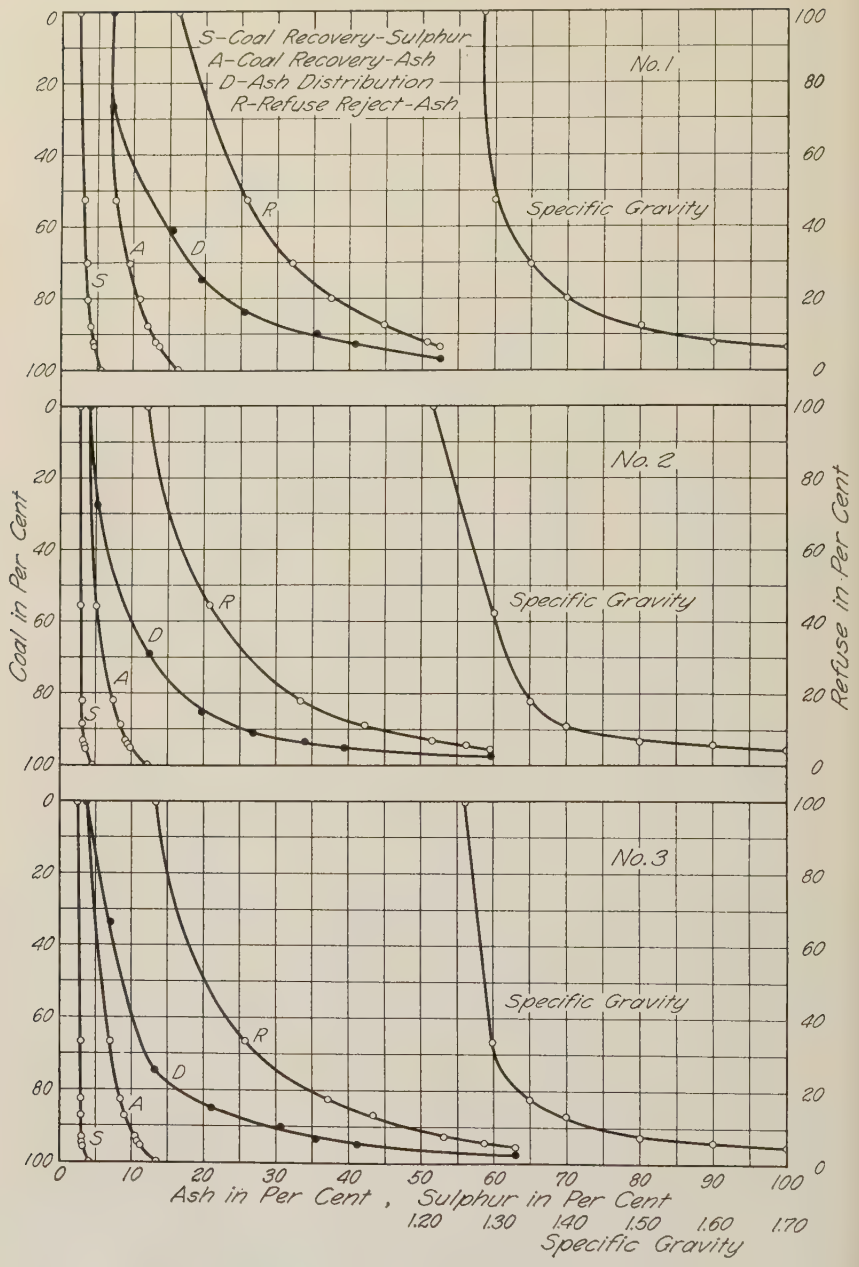

FIG. 4. WASHABILITY CURVES, MINE A, TIPPLE SAMPLE P

(Moisture Free)

Coal sizes: No. 1, 5 x 3 in.; No. 2, 3 x 1½ in.; No. 3, 1½ x ¾ in.

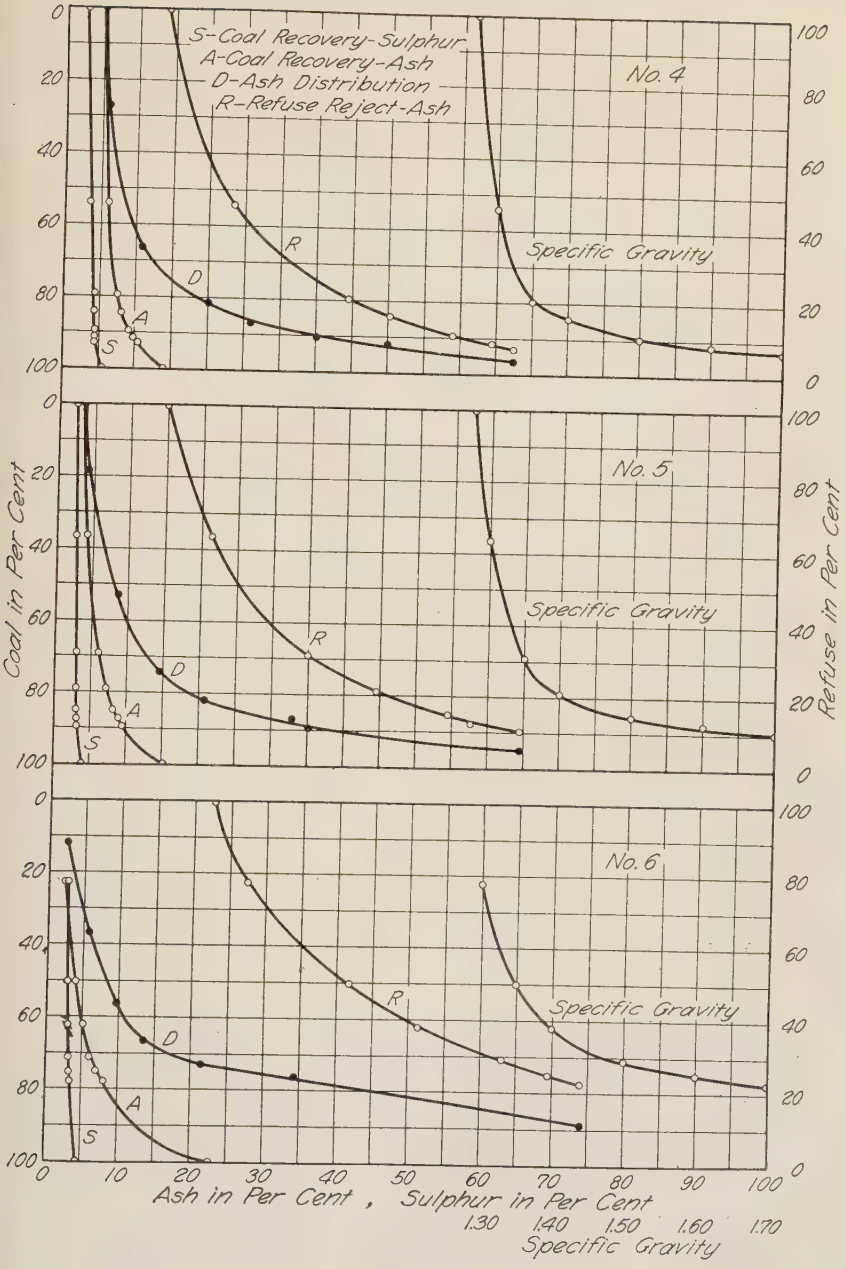

FIG. 4 (CONTINUED). WASHABILITY CURVES, MINE A, TIPPLE SAMPLE P

(Moisture Free)

Coal sizes: No. 4, ¾ x ¼ in.; No. 5, ¼ x ⅛ in.; No. 6, ⅛ x 0 in.

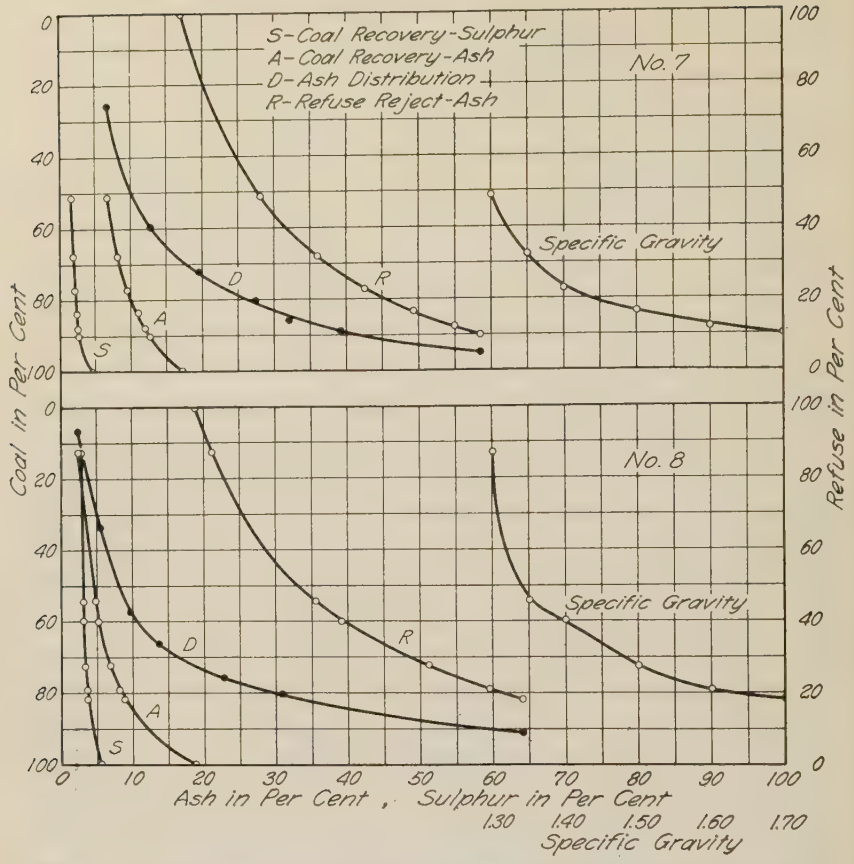

FIG. 4 (CONCLUDED). WASHABILITY CURVES, MINE A, TIPPLE SAMPLE P

(Moisture Free)

Size 5 x 3 in. crushed through rolls set at ¾ in.: No. 7, + 3/16 in.; No. 8, — 3/16 in.

sizes were riffled down for ease in screening and in handling for float-and-sink analyses. The larger sizes are cleaner than the smaller sizes except for the 5 x 3-in. coal. It is to be noted that although Sample P is partly made up of crushed lump, over 90 per cent of the sample is coarser than ¼ in. Sample Q consists of particles over 75 per cent of which are coarser than 48 mesh, or well within the range of sizes that modern cleaning processes are able to treat.

Washability curves from 1 to 13, inclusive, shown in Figs. 4 and 5, give the results obtained, and are made up for the samples treated as follows: The results of the float-and-sink treatment of all sizes

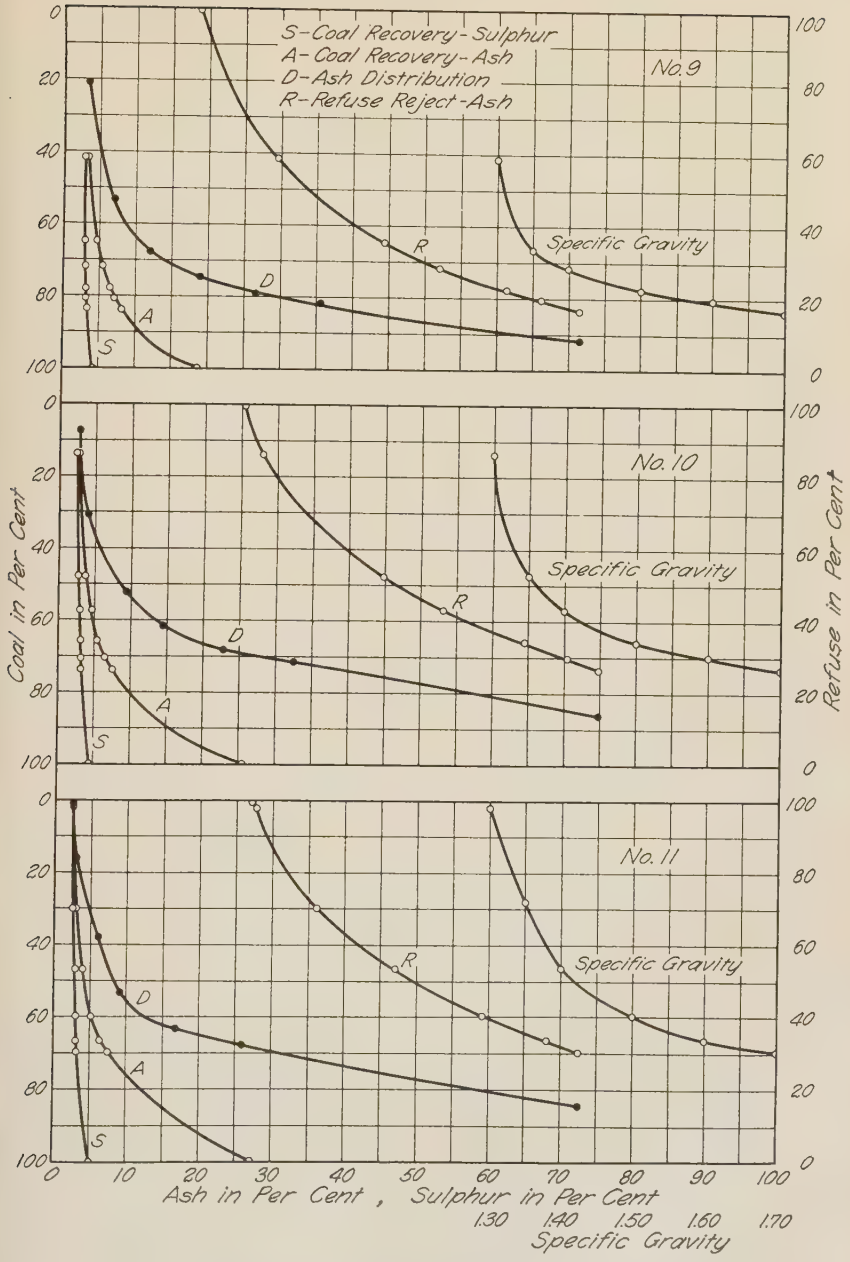

FIG. 5. WASHABILITY CURVES, MINE A, TIPPLE SAMPLE Q

(Moisture Free)

Coal sizes: No. 9, ⅛ in. x 20 mesh; No. 10, 20 x 48 mesh; No. 11, 48 x 100 mesh.

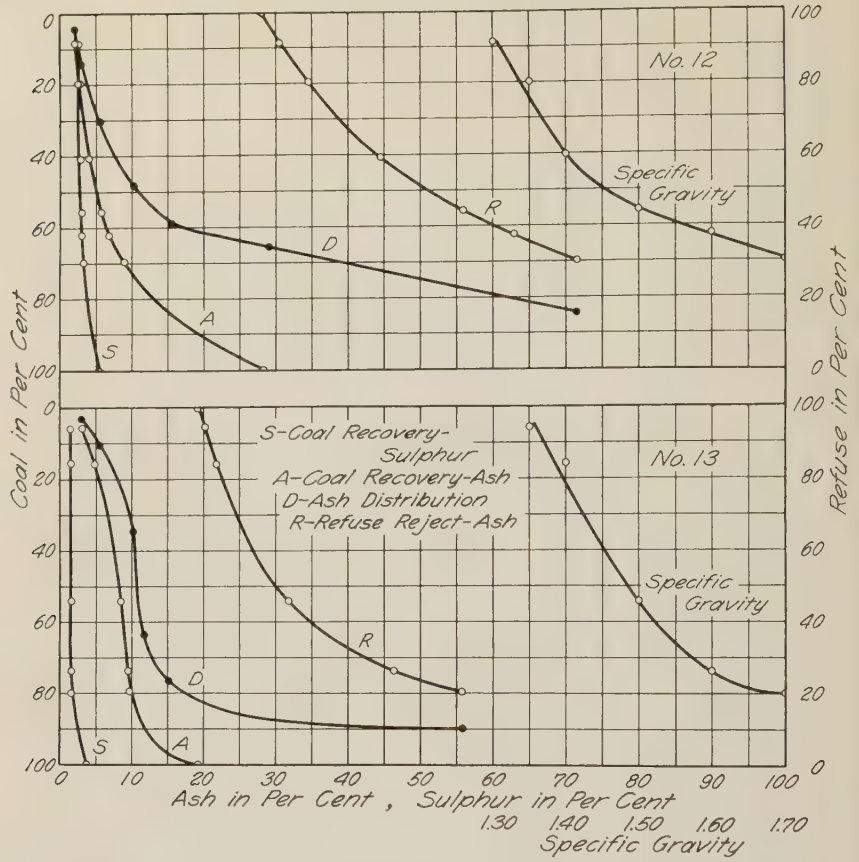

FIG. 5 (CONCLUDED). WASHABILITY CURVES, MINE A, TIPPLE SAMPLE Q

(Moisture Free)

Coal sizes: No. 12, 100 x 200 mesh; No. 13, 200 x 0 mesh.

of Sample P are shown by curves 1-6. The 5 x 3-in. size crushed to ¾ in. and re-treated is shown by curves 7 and 8. The results of the treatment of all sizes of Sample Q are shown by curves 9 to 13, Fig. 5. The study of these curves shows that there is a gradual flattening out of the ash curves, progressively pronounced the finer the size, which indicates that the impurities are freed from the coal substance in the finer sizes. As will be seen from these curves for Sample P, a recovery of 90 per cent can be made in all sizes except the 5 x 3-in. with an ash content of less than 10 per cent. For the 5 x 3-in. size, the ash content for a 90 per cent recovery would be 12 per cent. This

size crushed and re-treated can be made to give a much cleaner product.

The reduction in the percentage of sulphur, as predicted from the study of the sulphur analyses of the mine samples, was not much over 1 per cent in all sizes. Most of the sulphur that was removed was in the form of lump pyrite.

The curves for sample Q show that this duff coal could be cleaned with a recovery of about 75 per cent, and with an ash content for the clean coal of about 8 per cent. The curves show very well that practically all impurities are free from the coal substance.

Data relating to raw coal samples tested are as follows:

COAL FROM MINE A

Washability Curve No.	Size	Raw Coal			Lightest Coal		
		Ash per cent	Sulphur per cent	Moisture per cent	Sp. Gr.	Ash per cent (Moisture free)	Sulphur per cent (Moisture free)
		Tipple Sample P					
1.....	5 × 3 in.	14.3	5.00	12.3	1.284	7.33	2.48
2.....	3 × 1½ in.	11.7	4.03	12.3	1.265	4.29	2.72
3.....	1½ × ¾ in.	11.8	3.77	12.3	1.263	3.94	2.47
4.....	¾ × ¼ in.	12.3	4.82	12.3	1.269	5.25	2.88
5.....	¼ × ⅛ in.	13.2	3.52	12.3	1.275	3.58	2.44
6.....	⅛ × 0 in.	20.0	4.04	12.3	.....	....	....
	5 × 3 in. Portion Crushed with Rolls Set at ¾ in.						
7.....	+3/16 in.	15.2	4.22	12.3	.....	....	....
8.....	−3/16 in.	16.6	4.83	12.3	.....	....	....
		Tipple Sample Q					
9.....	⅛ in. × 20 mesh	16.6	3.77	12.3	.....	....	....
10.....	20 × 48 mesh	22.4	3.98	12.3	.....	....	....
11.....	48 ×100 mesh	23.9	4.55	12.3	.....	....	....
12.....	100 ×200 mesh	24.7	4.87	12.3	.....	....	....
13.....	200 × 0 mesh	16.8	3.32	12.3	.....	....	....

The summary of the float-and-sink analyses is given in Table 5.

Table 6, the theoretical yield table, is compiled to show what the yields of all sizes would be at a certain selected recovery or gravity which was taken as 1.50 specific gravity for the larger sizes and 1.70 for the smaller. Table 7 is compiled from these theoretical results to show what results could be expected from a daily production of 1000 tons with all analyses calculated to the moisture content of the coal as mined, which is 12.3 per cent. Any change in the theoretical yields to get a coal of a lower or higher ash content would, of course, change this table. These two tables indicate that with a recovery of 90 per cent, a coal of less than 10 per cent ash would be the resultant product.

Table 8 gives some interesting information on the distribution of the various sulphur forms in float-and-sink fractions. The progressive increase of total sulphur from the lightest fraction analyzed, or the purest coal, to the heaviest fractions, or refuse, is paralleled by the analyses for pyritic and sulphate sulphur. The organic sulphur is just the opposite, except for one size, showing a concentration of

Table 5

Summary of Float-and-Sink Results—Mine A

Per cent by weight and per cent ash and sulphur in fractions at different specific gravities (moisture free)

Sample P

Size	Per cent of Sample	<1.30 Sp. Gr.			1.30–1.35 Sp. Gr.			1.35–1.40 Sp. Gr.			1.40–1.50 Sp. Gr.			1.50–1.60 Sp. Gr.			1.60–1.70 Sp. Gr.			>1.70 Sp. Gr.			Total		
		Wt.	Ash	S	Wt.	Ash	S	Wt.	Ash	S	Wt.	Ash	S	Wt.	Ash	S	Wt.	Ash	S	Wt.	Ash	S	Wt.	Ash	S
5 x 3 in.*.....	30.7	52.30	7.52	3.34	17.90	15.55	4.57	10.10	19.52	4.61	7.51	25.47	6.48	4.70	35.68	10.95	1.15	40.70	13.85	6.35	52.60	23.95	100	16.25	5.71
3 x 1½ in.....	33.3	55.50	5.16	2.91	26 70	12.45	3.78	6.65	19.80	4.11	4.45	26.75	5.55	1.35	34.15	9.00	0.88	39.50	11.05	4.47	59.43	27.10	100	12.15	4.59
1½ x ¾ in.....	16.3	66.50	7.27	3.07	16.15	13.36	3.25	4.58	21.20	4.98	5.65	30.90	5.54	1.50	35.45	7.54	1.28	41.30	7.60	4.34	63.00	22.40	100	13.48	4.28
¾ x ¼ in.....	12.1	54.00	6.05	3.58	25.40	10.75	5.43	4.93	20.20	5.93	5.10	26.10	6.26	2.27	35.30	7.38	1.34	45.00	6.73	6.96	62.40	18.40	100	14.09	5.46
¼ x ⅛ in.....	2.5	36.65	4.20	2.84	32.54	8.62	3.24	9.88	14.60	3.94	6.16	20.90	4.41	2.46	33.00	4.69	2.10	35 20	4.81	10.21	64.60	10.40	100	15.12	4.02
⅛ x 0 in.....	5.1	22.60	2.47	2.71	27.70	5.80	3.34	11.70	9.76	3.57	8.90	13.65	4.27	3.90	21.60	4.13	2.90	34.40	5.55	22.30	74.00	8.87	100	22.81	4.64
5 x 0 in.....	100.0	53.9	6.39	3.14	22.3	12.50	4.17	7.5	19.10	4.53	5.9	25.70	5.93	2.7	33.30	9.25	1.30	37.70	9.30	6.4	61.10	20.8	100	14.64	4.98

Sample Q

⅛ in. x 20 mesh	49.6	41.2	3.50	3.01	23.2	7.20	3.33	6.9	12.10	3.42	6.2	19.0	3.97	2.8	26.70	5.77	3.0	35.70	5.75	16.7	71.60	9.04	100	18.94	4.34
20 x 48 mesh...	28.8	13.8	3.05	2.51	33.5	4.18	3.12	9.8	9.57	3.29	8.8	14.65	4.44	4.4	22.70	5.33	3.0	32.40	4.90	26.7	74.80	7.40	100	25.61	4.48
48 x 100 mesh..	9.8	1.8	2.50	2.54	27.5	3.07	2.65	17.2	6.27	3.64	13.0	9.30	3.81	6.8	17.10	3 85	3.2	26.00	5.26	30.5	72.50	9 23	100	27.3	5.15
100 x 200 mesh	3.9	8.4	2.02	2.65	11.3	2.92	3.17	20.8	5.40	3.18	15.0	10.30	3.38	6 6	15.60	3.36	7.2	29.10	4.33	30.7	71.50	10.80	100	28.15	5.56
200 x 0 mesh...	7.9	0.0	0.00	0.00	5.7	3.14	1.49	9.8	5.68	1.53	38.5	10.15	1.66	19.4	11.83	1.78	6.5	15.36	2.30	20.1	55 85	11 93	100	19.23	3.79
⅛ x 0 in.....	100.0	24.9	3.41	2.89	24.8	5.40	3.10	9.5	9.16	3.27	10.4	13.95	3.36	5.2	19.00	4.23	3.5	30.10	4.86	21.7	71.90	8.84	100	22.06	4.46
																							100	14.64	4.98
Total P.....	98.3																						100	22.06	4.46
Total Q.....	1.7																						100	14.76	4.97
Total R. O. M.†	100.0																								

*Coal that passed through a crusher set at 5 inches and over a 3-inch round hole screen.
†This total R. O. M. calculation is from the composite of Sample P and Sample Q of this mine.

TABLE 6

THEORETICAL YIELDS—MINE A

(Moisture Free)

Size	Per cent of Total	Raw Coal		Yield per cent		Separation at Sp.Gr.	Coal		Refuse	
		Ash per cent	S per cent	Coal	Refuse		Ash	S	Ash	S
Sample P (5-in. x Duff)										
5 x 3 in.	30.7	16.3	5.7	87.8	12.2	1.50	12.2	4.0	44.7	18.0
3 x 1½ in.	33.4	12.2	4.6	93.3	6.7	1.50	9.3	3.4	51.6	21.4
1½ x ¾ in.	16.3	13.5	4.3	92.9	7.1	1.50	10.4	3.3	53.3	16.7
¾ x ¼ in.	12.1	14.1	5.5	89.4	10.6	1.50	9.3	4.4	54.2	14.6
¼ x ⅛ in.	2.5	15.1	4.0	89.8	11.2	1.70	9.5	3.3	64.6	10.4
⅛ x 0 in.	5.1	22.8	4.6	77.7	22.3	1.70	8.1	3.4	74.0	8.9
Sample Q (Duff Coal)										
⅛ in. x 20 mesh.	49.6	18.9	4.3	83.3	16.7	1.70	8.3	3.4	71.6	9.0
20 x 48 mesh.	28.3	25.6	4.5	73.3	26.7	1.70	7.7	3.4	74.8	7.4
48 x 100 mesh.	9.8	27.3	5.2	69.5	30.5	1.70	7.4	3.3	72.5	9.2
100 x 200 mesh.	4.0	28.2	5.6	69.3	30.7	1.70	9.0	3.2	71.5	10.8
200 x 0 mesh.	7.9	19.2	3.8	79.9	20.1	1.70	10.0	1.7	55.9	11.9

TABLE 7

YIELDS FROM 1000 TONS OF RUN-OF-MINE COAL PASSED THROUGH A CRUSHER SET AT 5 INCHES—MINE A

Size	Coal, Cleaned					Total Coal Yield per cent	Refuse	
	Tons	M*	Ash	S	B.t.u.		Tons	Per Cent
5 x 0 in.	901	12.3	8.9	3.2	11190	90.1	99	9.9
5 in. x Duff†.	886	12.3	9.0	3.2	11180	90.1	99	9.9
Duff x 0 in.	15	12.3	7.2	2.9	11470			

*The analyses are for a moisture content of 12.3 per cent, the average moisture in the coal as mined. The moisture in the cleaned coal will depend upon the method of cleaning used.
†Duff is coal that passed through a 5/32-in. screen at the mine.

organic sulphur in the cleanest coal. This concentration of pyritic sulphur and, to a lesser extent, of sulphate sulphur in the heavier fractions is thus counterbalanced to a slight extent by the lighter fractions having a concentration of organic sulphur.

The refuse in the float-and-sink fractions has a considerably lower ash-softening temperature than the pure coal fractions. Elimination of this refuse tends to increase the fusibility of the ash of the cleaned product considerably.

TABLE 8

SULPHUR DISTRIBUTION AND SOFTENING TEMPERATURE OF ASH OF SELECTED FLOAT-AND-SINK FRACTIONS—MINE A

(Moisture Free)

Size	Fractions	Sulphate Sulphur	Pyritic Sulphur	Organic Sulphur	Total Sulphur	Softening Temperature of Ash deg. F.
3 x 1½ in.	1.30 Float	0.02	0.88	2.01	2.90	
	1.30–1.35 Float	0.04	1.69	2.05	3.78	
	1.35–1.40 Float	0.05	2.21	1.85	4.11	
	1.40–1.50 Float	0.07	3.37	2.11	5.55	
	1.50–1.60 Float	0.10	6.40	2.49	9.00	
	1.60–1.70 Float	0.25	9.12	1.68	11.05	
	1.70 Sink	0.43	26.07	0.60	27.10	
1½ x ¾ in.	1.30 Float	0.02	0.87	2.18	3.07	2234
	1.30–1.35 Float	0.06	1.56	1.32	3.25	1932
	1.35–1.40 Float	0.08	3.13	1.77	4.98	1990
	1.40–1.50 Float	0.09	3.20	2.25	5.54	2100
	1.50–1.60 Float	0.14	5.30	2.10	7.54	1968
	1.60–1.70 Float	0.17	5.54	1.89	7.60	1932
	1.70 Sink	0.37	21.00	1.03	22.40	1894
¾ x ¼ in.	1.30 Float	0.02	0.80	2.76	3.58	
	1.30–1.35 Float	0.02	1.25	4.16	5.43	
	1.35–1.40 Float	0.05	2.34	3.54	5.93	
	1.40–1.50 Float	0.06	2.92	3.28	6.26	
	1.50–1.60 Float	0.09	4.57	2.72	7.38	
	1.60–1.70 Float	0.13	5.18	1.42	6.73	
	1.70 Sink	0.34	12.95	5.01	18.40	
⅛ in. x 20 mesh	1.30 Float	0.02	0.72	2.27	3.01	
	1.30–1.35 Float	0.04	1.17	2.12	3.33	
	1.35–1.40 Float	0.05	1.65	1.72	3.42	
	1.40–1.50 Float	0.06	2.30	1.61	3.97	
	1.50–1.60 Float	0.09	3.31	2.37	5.77	
	1.60–1.70 Float	0.18	3.34	2.32	5.75	
	1.70 Sink	0.39	7.00	1.65	9.04	
1½ x ¾ in.	1.50 Float					2010
	1.50 Sink					1920

Conclusions

This coal because of its hardness would stand up well under preparation methods with little degradation of the commercial sizes which are desirable in Illinois coals.

Comparatively little sulphur could be eliminated by any cleaning process.

Although there is some flattening out of the D curve in the finer sizes as compared with the larger sizes, it is doubtful whether there would be enough improvement in the coal to justify crushing finer than 3 inches before treatment.

From a study of the ash recovery curves, it is apparent that coal of almost any desired ash content could be made, ranging from about 5 per cent ash to the average ash of the sample. The final ash desired is determined by the use to which the coal would be put, and by

economic considerations as to the yield. It would seem desirable to aim at producing a coal of less than 10 per cent ash with a recovery of about 90 per cent for the following reasons:

(a) The recovery is good and the breaks or flattening out of the curves are more pronounced at or near 90 per cent recovery.

(b) The refuse would have little or no heating value, having ash values of from 45 to 75 per cent, depending on the size treated.

15. *Mine B, Coal No. 7, Marshall County.*—The coal is hard and breaks in irregular lumps, which is no doubt due to the fact that no undercutting is done and the coal is blasted from the solid. Pronounced bedding planes are apparent and with the use of cutting machines lump coal of flat tabular pieces would undoubtedly be produced as a considerable portion of the coal mined. The typical banded structure of alternating bright and dark coal layers is characteristic of this bed with the dark coal layers constituting the greater portion of the bed.

The bed averages about 40 inches in thickness, with a minimum of about 36 inches and a maximum of about 44 inches.

Impurities

A persistent pyritic shale band ⅛ inch to 2 inches thick is found about eight inches from the floor. The band is locally called "the blue band" although it bears no resemblance to the blue band of the No. 6 coal in the southern Illinois field. This band is found over a considerable area and is one of the keymarks of this bed. It is shown in Fig. 6 in all three face sections. Several other thin bands of shale, pyrite, bone, and charcoal are found, but the columnar sections show no definite continuity between places sampled, as in the lower band. There is some deposition of calcite along vertical cleavage planes.

The roof is soapstone and stands up fairly well. There may be some of this roof rock mixed with the coal from local falls. The bottom clay is medium hard and lies fairly flat. Not much of this material should get mixed with the coal during mining operations.

Mine Samples

Three samples were taken as shown in Fig. 6 with the corresponding increment samples as marked for each face section.

The average mine moisture is 15.6 per cent, which is about the average for this bed over a considerable area. The ash and sulphur analyses are high. An interesting fact is brought out from a study

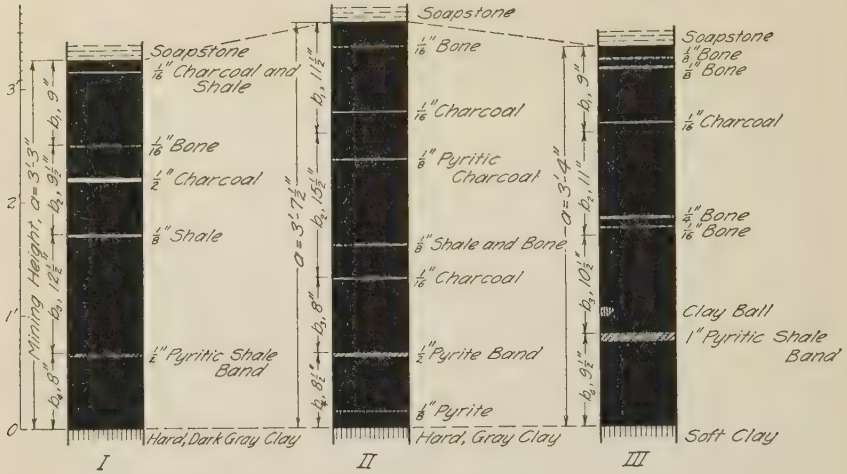

Fig. 6. Face Sections of No. 7 Coal, Marshall County, Mine B

of the increment analyses, which is that the bench of coal shown as b3 in each face section contains about 10 per cent less ash than any of the other benches. This particular bench appears to be consistently of good quality.

The calorific value of the coal as mined will average about 10 000 B.t.u. The softening temperature of the coal ash is low, falling in Class 3 and being around 2100 deg. F.

The total sulphur is high in all samples with the organic sulphur constituting from 50 to 75 per cent of this total, which indicates that only about 25 per cent of the total sulphur could be eliminated by coal cleaning processes.

Tipple Sample

Since this sample was taken at country banks with no facilities for sizing, a run-of-mine sample was taken for shipment to the laboratory. The composite sample from the three small mines consisted of 2700 pounds of coal, and is designated Sample P.

Test Procedure and Washability Analyses

In Table 10 are given the results of the screen analyses of this mine. The 6-inch lump constitutes only 5 per cent of the total sample which is undoubtedly due to the method of mining this coal. With a different system of mining, a considerably greater percentage of lump coal could be expected.

Table 9

Analyses of Mine Samples—Mine B

As Received

Sample Number	Moisture	V. M.	F. C.	Ash	Total Sulphur	Sulphate Sulphur	Pyritic Sulphur	Organic Sulphur	Calculated B.t.u.	Softening Temperature of Ash deg. F.
BIa	15.48	36.20	30.22	18.10	5.00	0.10	2.71	2.19	9 848	2120
BIIa	14.19	41.31	30.53	13.97	3.43	0.18	1.81	1.44	10 794	2100
BIIIa	15.44	33.02	31.90	19.64	5.03	0.10	3.40	1.53	9 616	
BIb1	15.75	31.05	33.12	20.08	3.44	0.08	1.83	1.53	9 564	1980
BIb2	14.64	27.89	37.78	19.69	2.43	0.09	0.84	1.50	9 768	2120
BIb3	15.83	37.71	35.80	10.66	2.85	0.04	1.06	1.75	10 822	2252
BIb4	15.68	32.87	33.33	18.12	7.49	0.11	5.50	1.88	10 142	2189
BIIb1	15.40	34.21	40.00	10.38	3.01	0.16	0.93	1.92	10 910	2050
BIIb2	15.65	32.14	34.02	18.18	3.42	0.03	1.46	1.92	9 828	2020
BIIb3	14.97	41.26	36.49	7.28	2.65	0.17	0.68	1.80	11 393	2110
BIIb4	15.75	30.78	32.11	21.35	7.41	0.15	4.84	2.42	9 293	2070
BIIIb1	16.70	32.36	31.12	19.82	2.95	0.04	1.13	1.78	9 502	
BIIIb2	16.28	33.93	32.21	17.58	1.98	0.20	0.40	1.38	9 872	
BIIIb3	16.67	37.75	35.95	9.63	2.37	0.04	0.87	1.46	10 861	
BIIIb4	15.59	33.88	33.90	16.63	7.80	0.15	5.18	2.47	9 929	

Suffix a indicates complete channel sample.
Suffix b indicates increment samples; see Fig. 6.

TABLE 10

SCREEN ANALYSIS—MINE B

Sample P

Size	Weight per cent	Cumulative Weight per cent	Ash per cent (Moisture Free)	Sulphur per cent (Moisture Free)
6-in. lump	5.0	5.0	20.18	5.05
6 x 3 in.	22.8	27.8	19.84	4.92
3 x 1½ in.	23.7	51.5	19.34	5.06
1½ x ¾ in.	16.6	68.1	20.43	5.86
¾ x ⅜ in.	11.7	79.8	21.87	5.20
⅜ x 3/16 in.	5.4	85.2	21.40	4.99
3/16 in. x 10 mesh	7.6	92.8	24.53	4.66
10 x 20 mesh	2.6	95.4	30.86	5.05
20 x 48 mesh	2.3	97.7	31.82	5.26
48 x 100 mesh	0.8	98.5	40.20	5.37
100 x 200 mesh	0.8	99.3	34.85	5.12
200 x 0 mesh	0.7	100.0	33.80	4.74
Totals and averages	100.0		23.06	5.20

The average ash percentage increases as the size decreases down to 100 mesh, and then decreases. This is rather unusual and indicates that the impurities break rather easily into fine particles down to about 100 mesh and then do not break any finer to produce dust as easily as does the coal substance.

The average sulphur percentages are about the same for all sizes.

All sizes given in Table 10 were subjected to float-and-sink procedure except the 6-inch lump and the three finest sizes of which a composite sample (48 mesh x 0) was run. The three sizes 48 x 100, 100 x 200, and 200 x 0 mesh were screened to determine their weight percentage and an ash and sulphur determination was made on each size.

Washability curves 14 to 22 inclusive, Fig. 7, give the results obtained on this coal. As can quickly be seen from these curves, the coal is one that is very hard to benefit by cleaning. There is a high percentage of middling material and the coal in even the lighter fractions carries considerable ash and sulphur. In order to get the ash down to a reasonable figure, at least 50 per cent of the coal would have to be discarded. In order to show what could be expected from this coal as compared with the other coals tested, Yield Tables 12 and 13 were compiled. Table 11, giving the summary of the float-and-sink results, shows very clearly how this high ash middling material is found in practically all fractions in considerable quantity for all sizes.

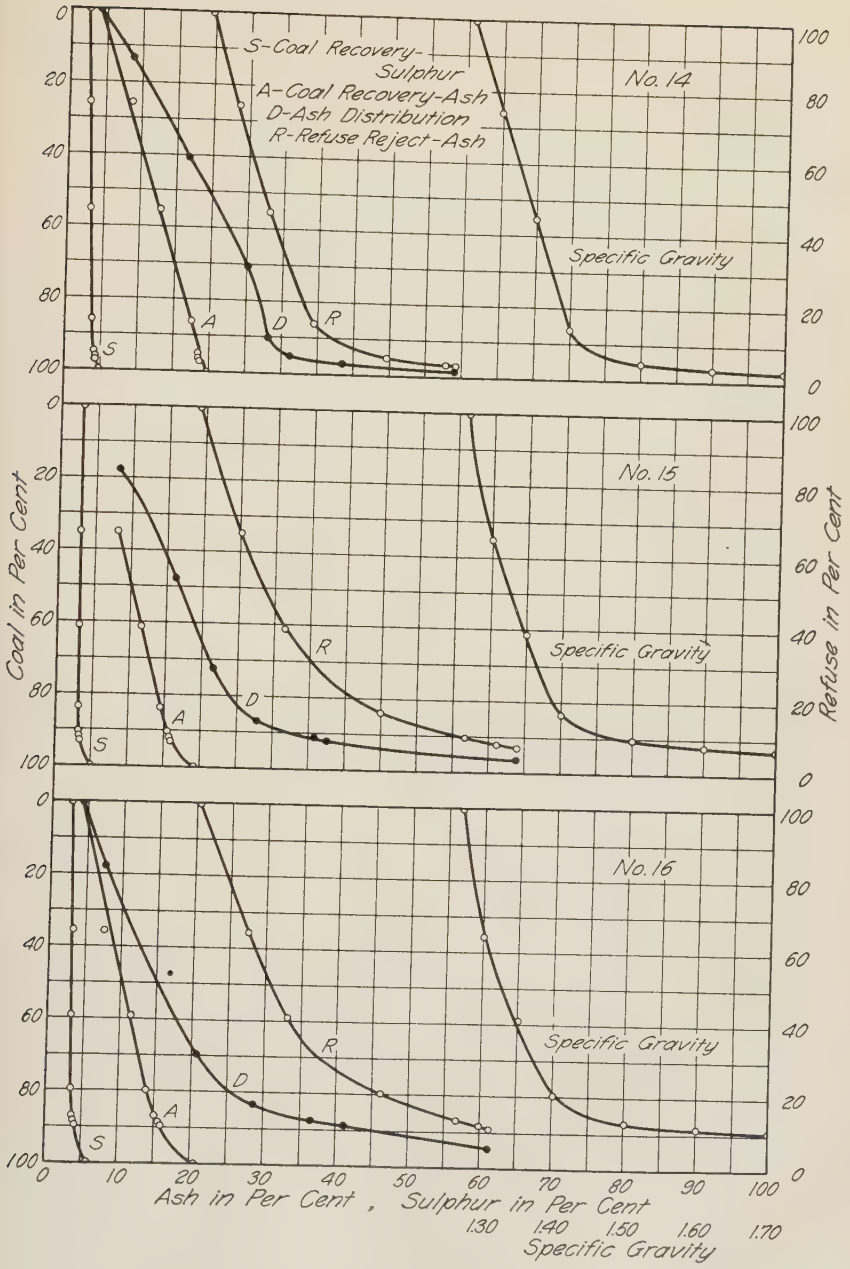

FIG. 7. WASHABILITY CURVES, MINE B, TIPPLE SAMPLE P

(Moisture Free)

Coal sizes: No. 14, 6 x 3 in.; No. 15, 3 x 1½ in.; No. 16, 1½ x ¾ in.

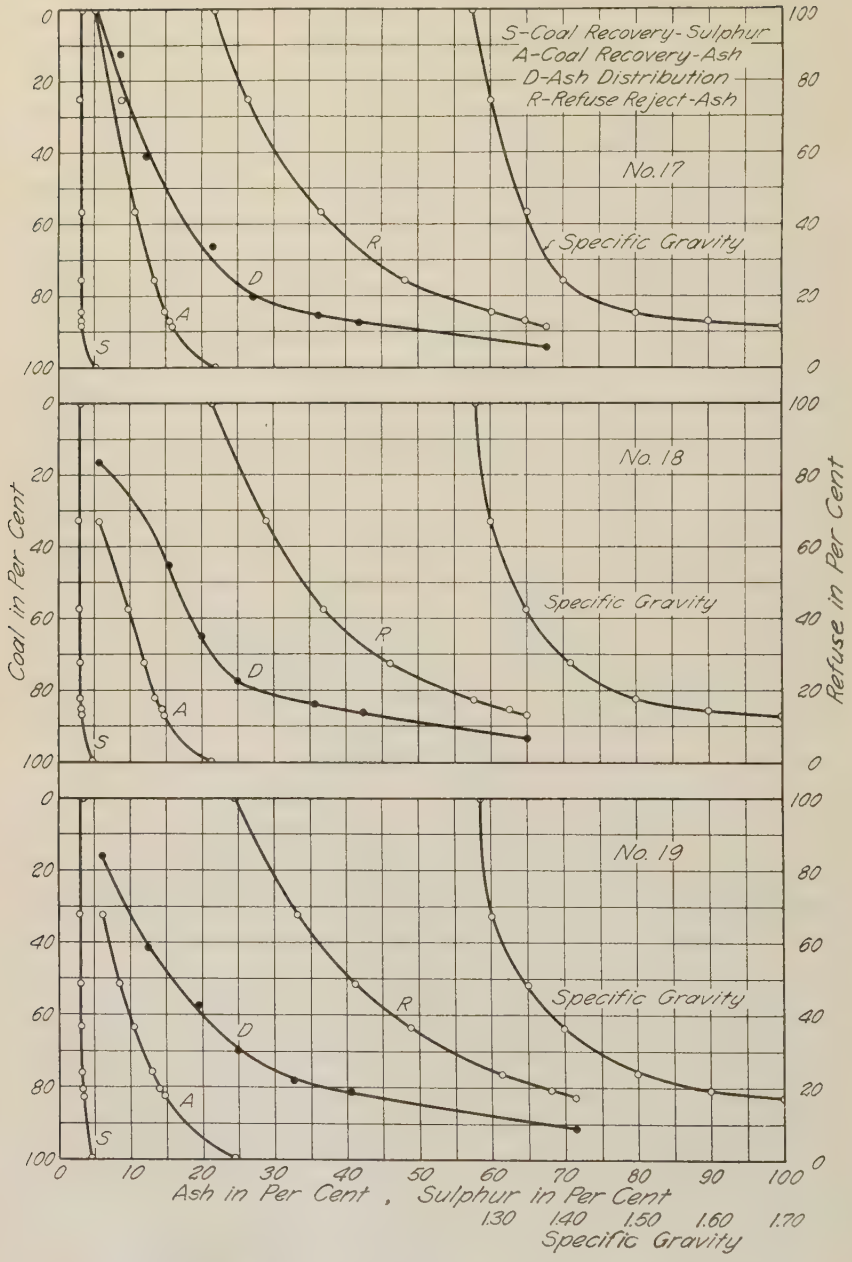

FIG. 7 (CONTINUED). WASHABILITY CURVES, MINE B, TIPPLE SAMPLE P

(Moisture Free)

Coal sizes: No. 17, ¾ x ⅜ in.; No. 18, ⅜ x 3/16 in.; No. 19, 3/16 in. x 10 mesh.

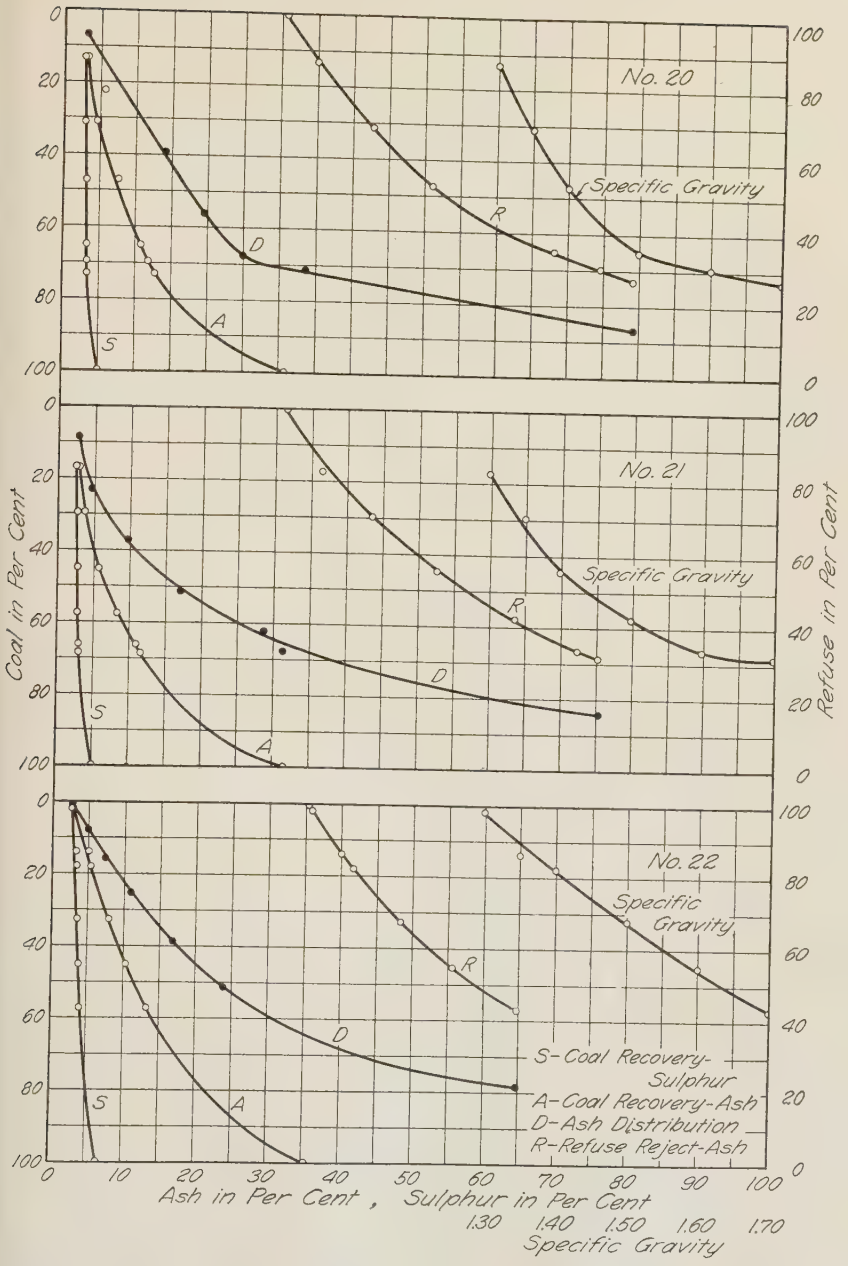

FIG. 7 (CONCLUDED). WASHABILITY CURVES, MINE B, TIPPLE SAMPLE P

(Moisture Free)

Coal sizes: No. 20, 10 x 20 mesh; No. 21, 20 x 48 mesh; No. 22, 48 x 0 mesh.

Table 11

Summary of Float-and-Sink Results—Mine B

Per cent by weight and per cent ash and sulphur in fractions at different specific gravities
(moisture free)

Size	Per cent of Sample	<1.30 Sp. Gr.			1.30–1.35 Sp. Gr.			1.35–1.40 Sp. Gr.			1.40–1.50 Sp. Gr.			1.50–1.60 Sp. Gr.			1.60–1.70 Sp. Gr.			>1.70 Sp. Gr.			Total		
		Wt.	Ash	S	Wt.	Ash	S	Wt.	Ash	S	Wt.	Ash	S	Wt.	Ash	S	Wt.	Ash	S	Wt.	Ash	S	Wt.	Ash	S
6 x 3 in.	24.0	25.6	8.72	2.92	29.4	16.81	3.45	31.0	25.15	4.68	8.8	28.20	7.05	1.9	31.20	10.30	0.3	38.62	10.60	3.0	54.25	27.90	100	19.84	4.92
3 x 1½ in.	25.0	34.7	8.19	2.96	26.4	16.30	3.12	22.8	21.70	3.50	6.6	27.90	4.38	1.6	35.90	8.14	0.8	37.45	11.73	7.1	64.00	26.85	100	19.34	5.06
1½ x ¾ in.	17.5	35.7	7.69	3.25	23.3	17.40	3 58	20.8	20.62	3.66	7.3	28.40	4.63	1.6	36.40	5.72	0.9	41.20	8.69	10.4	61.20	24.90	100	20.43	5.86
¾ x ⅜ in.	12.3	25.0	8.69	2.89	31.5	12.16	3.25	19.3	21.48	3.12	8.7	27.32	3.82	2.5	36.19	5.26	1.4	41.90	6.57	11.6	67.70	19.75	100	21.87	5.20
⅜ x 3/16 in.	5.7	32.9	5.87	2.99	24.8	15.41	3.24	14.9	20.10	3.36	9.8	25.10	4.32	3.2	35.80	4.77	1.4	42.40	5.27	13.0	65.0	15.55	100	21.40	4.99
3/16 in. x 10 mesh	8.0	32.2	6.07	3.00	19.1	12.50	3.41	12.4	19.60	3.49	12.6	25.00	3.89	4.5	32.70	4.60	2.0	40.40	5.57	17.2	71 40	10.45	100	24.53	4.66
10 x 20 mesh	2.7	13.1	3.14	2.83	18.1	5.54	3.06	15.6	14.00	3.69	18 4	19.13	3.61	4.3	25.00	3.84	3.3	33 60	4.05	27.2	79.20	9.53	100	30.86	5.05
20 x 48 mesh	2.4	16.8	2.95	2.75	12.8	4.98	2.94	15.0	10.10	3.26	13.1	17.30	3.54	8.6	28.90	3.99	2.3	31.41	4.27	31.4	75.40	9.64	100	31.82	5.26
48 x 0 mesh	2.4	1.3	2.88	2.88	12.1	5.27	3.62	4.2	7.46	3.76	14.5	11.12	4.22	12.7	17.00	4.81	12.1	24.12	5.32	43.1	64.70	10.25	100	35.57	6.92
6 x 0 mesh	100.0	29.7	7.70	3.00	25.4	15.40	3.36	22.0	22.10	3.89	8.8	25.94	4.84	2.6	31.53	6.30	0.95	33.70	6.80	10.4	66.02	18.50	100	23.06	5.20
6-in. Lump	5.0																						100	20.18	5.05
6 x 0 in.	95.0																						100	23.06	5.20
Total R. O. M.	100.0																						100	22.96	5.19

TABLE 12

THEORETICAL YIELDS—MINE B

(6 x 0-in. Coal—Moisture Free)

Size	Per cent of Total	Raw Coal		Yield per cent		Separation at Sp.Gr.	Coal		Refuse	
		Ash per cent	S per cent	Coal	Refuse		Ash	S	Ash	S
6 x 3 in.	24.0	19.8	4.9	94.0	6.0	1.50	18.6	4.0	42.5	18.2
3 x 1½ in.	25.0	19.3	5.1	90.5	9.5	1.50	15.4	3.2	56.8	22.4
1½ x ¾ in.	17.5	20.4	5.9	87.1	12.9	1.50	15.0	3.5	56.7	21.4
¾ x ⅜ in.	12.3	21.9	5.2	84.5	15.5	1.50	14.8	3.2	60.2	16.2
⅜ x 3/16 in.	5.7	21.4	5.0	87.0	13.0	1.70	14.9	3.4	65.0	15.7
3/16 in. x 10 mesh	8.0	24.5	4.7	82.8	17.2	1.70	14.8	3.5	71.4	10.5
10 x 20 mesh	2.7	30.9	5.1	72.8	27.2	1.70	12.8	3.4	79.2	9.5
20 x 48 mesh	2.4	31.8	5.3	68.6	31.4	1.70	11.9	3.3	75.4	9.6
48 x 0 mesh	2.4	35.6	6.9	56.9	43.1	1.70	13.5	4.4	64.7	10.3

Data relating to raw coal samples tested are as follows:

COAL FROM MINE B, TIPPLE SAMPLE P

Washability Curve No.	Raw Coal Size	Raw Coal Ash per cent	Raw Coal Sulphur per cent	Raw Coal Moisture per cent	Lightest Coal Sp. Gr.	Lightest Coal Ash per cent (Moisture free)	Lightest Coal Sulphur per cent (Moisture free)
14	6 × 3 in.	16.7	4.15	15.6	1.261	4.01	2.58
15	3 × 1½ in.	16.3	4.27	15.6	1.265	....	3.02
16	1½ × ¾ in.	17.3	4.95	15.6	1.268	4.38	2.85
17	¾ × ⅜ in.	18.4	4.39	15.6	1.276	5.04	3.25
18	⅜ × 3/16 in.	18.1	4.21	15.6	1.281	....	3.37
19	3/16 in. × 10 mesh	20.7	3.93	15.6	1.286	....	3.59
20	10 × 20 mesh	26.0	4.26	15.6	.....	....	....
21	20 × 48 mesh	26.9	4.44	15.6	.....	....	....
22	48 × 0 mesh	30.0	5.84	15.6	.....	....	....

Conclusions

This coal is very difficult to improve by any cleaning process. Under present market conditions, it is doubtful if it would be commercially or economically feasible to produce a coal of low enough ash percentage to compete with other coals.

16. *Mine C, Coal No. 5, Peoria County.*—This coal is very hard and tends to break along the bedding planes in large, slabby lumps. The bedding planes generally are characterized by a thin deposit of mineral charcoal which in some instances is replaced by bony coal or pyrite. The dark coal substance (attritus) makes up by far the greater portion of the coal bed. There is no pronounced cleat and the coal tends to break with a conchoidal fracture when broken normal to the bedding planes.

The coal bed varies in thickness from about 42 to 52 inches, averaging approximately 48 inches.

TABLE 13

YIELDS FROM 1000 TONS OF RUN-OF-MINE COAL—MINE B

Coal, Not Cleaned						Coal, Cleaned						Total Coal Yield per cent	Refuse	
Size	Tons	M*	Ash	S	B.t.u.	Size in.	Tons	M*	Ash	S	B.t.u.		Tons	Per Cent
6-in. Lump.....	50	15.6	17.0	4.3	9 959	6 x 0	830	15.6	13.3	3.0	10 522	88.0	120	12.0
3-in. Lump.....	278	15.6	16.8	4.1	10 043	3 x 0	616	15.6	12.6	2.9	10 617	89.4	106	10.6
3-in. Lump.....	278	15.6	16.8	4.1	10 043	3 x 3/8	458	15.6	12.7	2.8	10 612	89.4	106	10.6
						3/8 x 0	158	15.6	12.0	3.0	10 694			

*The analyses are for a moisture content of 15.6 per cent, the average moisture in the coal as mined. The moisture in the cleaned coal will depend upon the method of cleaning used.

TABLE 14

SULPHUR DISTRIBUTION AND SOFTENING TEMPERATURE OF ASH OF SELECTED FLOAT-AND-SINK FRACTIONS—MINE B

(Moisture Free)

Size	Fractions	Sulphate Sulphur	Pyritic Sulphur	Organic Sulphur	Total Sulphur	Softening Temperature of Ash deg. F.
3 x 1½ in.....	1.30 Float	0.03	0.93	2.00	2.96	
	1.30–1.35 Float	0.06	1.20	1.86	3.12	
	1.35–1.40 Float	0.14	1.36	2.00	3.50	
	1.40–1.50 Float	0.24	2.30	1.84	4.38	
	1.50–1.60 Float	0.26	6.26	1.62	8.14	
	1.60–1.70 Float	0.26	9.92	1.55	11.73	
	1.70 Sink	0.41	22.70	3.75	26.85	
1½ x ¾ in.....	1.30 Float					
	1.30–1.35 Float					2035
	1.35–1.40 Float					2135
	1.40–1.50 Float					2130
	1.50–1.60 Float					2075
	1.60–1.70 Float					2075
	1.70 Sink					2030
						2218
¾ x ⅜ in.....	1.30 Float	0.16	1.48	1.25	2.89	
	1.30–1.35 Float	0.10	1.35	1.80	3.25	
	1.35–1.40 Float	0.07	1.39	1.65	3.12	
	1.40–1.50 Float	0.09	2.14	1.58	3.82	
	1.50–1.60 Float	0.15	3.69	1.41	5.27	
	1.60–1.70 Float	0.19	5.04	1.29	6.57	
	1.70 Sink	0.39	16.00	3.33	19.75	
10 x 20 mesh.....	1.30 Float	0.03	0.61	2.18	2.83	
	1.30–1.35 Float	0.07	0.96	2.03	3.06	
	1.35–1.40 Float	0.11	1.74	1.84	3.69	
	1.40–1.50 Float	0.12	1.73	1.76	3.61	
	1.50–1.60 Float	0.21	3.53	0.10	3.84	
	1.60–1.70 Float	0.21	2.88	0.96	4.05	
	1.70 Sink	0.41	8.71	0.41	9.53	
1½ x ¾ in.....	1.50 Float					
	1.50 Sink					2140
						2020

Impurities

The impurities, as shown in Fig. 8, are chiefly bands of bony coal, shale, and mineral charcoal. These bands vary from a streak to as much as four inches. They occur at irregular horizons and there is no particular band that is persistent over any considerable area as in the No. 6 or No. 7 coal. These bands, especially the mineral charcoal ones, frequently widen to massive pyrite lenses. There are also a considerable number of pyrite veins and veinlets running at all angles from the vertical to nearly horizontal across the coal face. There is found at times a peculiar formation of pyrite veins in this mine of dome-shaped structure which are locally called "horsebacks." These veins enter the coal bed from the floor, rise to about the middle of the bed and then gradually angle back to the floor again. They will vary in thickness from a streak to as much as four inches. A part of one is shown in Fig. 8 in face section II.

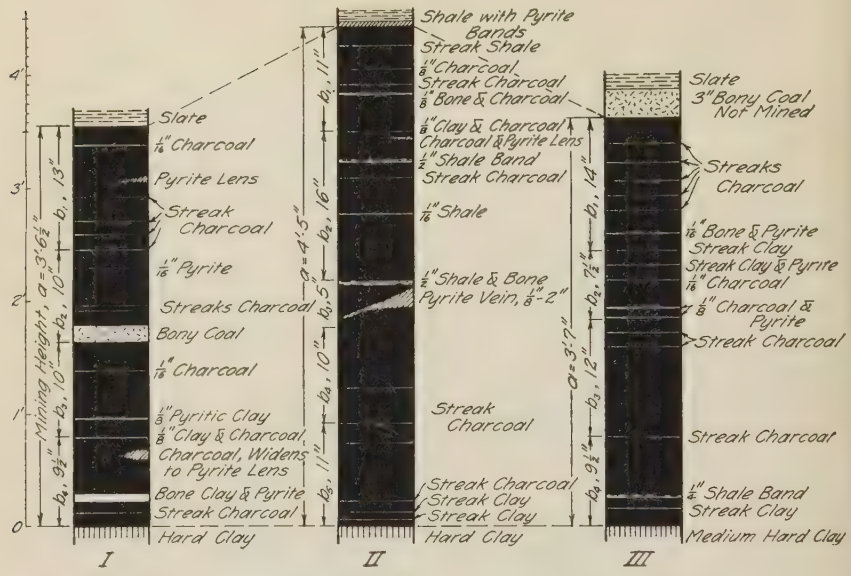

FIG. 8. FACE SECTIONS OF NO. 5 COAL, PEORIA COUNTY, MINE C

The roof is generally of a dark-colored hard slate. Thin bands of shale, pyrite, and at times bony coal are frequently found immediately overlying the coal. Some of these bands fall when the coal is removed from under them and there is some chance of this material being loaded out with the coal.

The floor is of a medium to hard clay; there is little opportunity for it to become mixed with the coal.

Mine Samples

Three places were sampled at this mine. At each place a complete channel sample and an increment sample were taken. These sections of the bed are shown in Fig. 8.

The average moisture of this bed was found to be 16.5 per cent. The ash and sulphur were high, although the total sulphur percentages were not as high as the number of pyrite veins would lead one to estimate. The best part of the bed seems to be the benches near the roof as represented by increment sample b1 for all face sections. The calorific value of the coal is low, averaging slightly less than 10 000 B.t.u. for the mine samples. The softening temperature of the coal ash varies from 1700 to 2200 deg. F., placing it in Class 3.

TABLE 15

ANALYSES OF MINE SAMPLES—MINE C

As Received

Sample Number	Moisture	V. M.	F. C.	Ash	Total Sulphur	Sulphate Sulphur	Pyritic Sulphur	Organic Sulphur	Calculated B.t.u.	Softening Temperature of Ash deg. F.
CIa	16.38	34.98	35.26	13.38	2.03	0.26	0.51	1.26	9 790	1944
CIIa	17.14	32.07	36.18	14.60	1.81	0.10	0.50	1.21	9 490	
CIIIa	15.50	36.13	34.75	13.62	3.25	0.31	1.63	1.31	9 840	1874
CIb1	16.71	42.14	32.74	8.41	1.87	0.04	0.57	1.26	10 610	1944
CIb2	17.69	35.31	34.24	12.76	2.55	0.04	1.29	1.24	9 600	2194
CIb3	17.50	33.76	33.49	15.25	2.15	0.23	0.67	1.25	9 200	2005
CIb4	16.56	33.30	35.68	14.45	1.96	0.25	0.35	1.36	9 480	2020
CIIb1	15.04	36.03	37.48	11.45	1.61	0.05	0.40	1.16	10 330	
CIIb2	16.83	36.25	27.67	19.25	2.67	0.15	1.10	1.42	8 620	
CIIb3	13.35	31.34	20.67	34.65	9.12	0.14	8.10	0.88	6 340	
CIIb4	18.00	35.18	33.36	13.45	1.81	0.17	0.35	1.29	9 540	
CIIb5	16.09	34.52	32.42	16.97	2.10	0.09	0.34	1.67	9 230	
CIIIb1	19.09	38.42	31.11	11.39	2.46	0.04	1.17	1.25	9 540	1938
CIIIb2	15.56	34.28	37.07	13.09	3.94	0.09	2.78	1.07	9 850	1868
CIIIb3	16.50	35.65	36.25	11.60	2.15	0.03	0.74	1.30	9 990	1907
CIIIb4	17.11	37.62	33.82	11.45	1.60	0.03	0.33	1.24	9 940	1704

Suffix a indicates complete channel sample.
Suffix b indicates increment samples; see Fig. 8.

TABLE 16

SCREEN ANALYSIS—MINE C

Sample P

Size	Weight per cent	Cumulative Weight per cent	Ash per cent (Moisture Free)	Sulphur per cent (Moisture Free)
6-in. lump	24.0	24.0	15.11	3.45
6 x 3 in.	12.0	36.0	18.10	3.87
3 x 1½ in.	18.2	54.2	16.65	4.00
1½ x ¾ in.	14.8	69.0	16.58	3.87
¾ x ⅜ in.	12.1	81.1	16.63	3.47
⅜ x 3/16 in.	4.4	85.5	17.74	3.05
3/16 in. x 10 mesh	7.4	92.9	18.60	2.95
10 x 20 mesh	2.7	95.6	16.67	3.21
20 x 48 mesh	2.6	98.2	19.03	3.47
48 x 100 mesh	0.9	99.1	24.80	1.98
100 x 200 mesh	0.4	99.5	23.41	3.03
200 x 0 mesh	0.5	100.0	28.80	2.07
Totals and averages	100.0		17.70	3.69

Tipple Sample

Three sizes are generally made at this mine, a 6-in lump, 6 x 2-in. modified egg (in making which only about one-fifth of the area of the 2-in. screen is left open), and 2-in. screenings. Loadings for the month previous to sampling were as follows:

6-in. lump ..... 24 per cent
6 × 2-in. modified egg ..... 59 per cent
2-in. screenings ..... 17 per cent

The following samples were taken for investigation at the laboratory:

6-in. lump ..... 2000 pounds
6 × 2-in. modified egg ..... 2000 pounds
2-in. screenings ..... 400 pounds

Test Procedure and Washability Analysis

The modified egg sample and 2-in. screenings were combined in the ratio that they were produced at the tipple and the screening tests made. The results are given in Table 16 with the lump percentage included in the calculations. Very little dust is made in preparing this coal, 86 per cent of the mine output being above 3/16 inch. As is characteristic of these coals the ash percentage increases with decrease in the size. There is little difference in the percentage of sulphur in the several sizes, although there is a slight concentration in the larger sizes.

The following procedure was followed in the float-and-sink analyses of this coal: All sizes from the 6 x 3-in. to 48 mesh and the 48 x 0-mesh were subjected to the float-and-sink procedure, treating the larger sizes in their entirety and quartering the smaller sizes down for ease in handling. The washability curves are numbered from 23 to 31 (see Fig. 9). A sample of the 48 x 0-mesh material was screened to get the weight percentage of the component sizes, and ash and sulphur determinations were made. The 6-in. lump was crushed, a portion being saved for ash and sulphur analyses, and then screened into the standard sizes for float-and-sink analysis, the results of which are shown by washability curves 32 to 35 inclusive, Fig. 10.

The washability curves for this coal show that it would be a difficult coal to treat in order to get a low ash coal with a reasonable recovery. This coal resembles the coal from Mine B very much in this respect, although coming from a different bed. There is a considerable amount of middling material in all fractions. In the larger sizes not only is there a high percentage of middling material but very little free refuse, the 6 x 3-in. size only having 0.6 per cent of sink material at 1.70 specific gravity with an average ash of 59.5 per cent. Table 17 and the washability curves show that there is some betterment of this condition in the finer sizes, indicating that after the coal is crushed fine enough, the impurities are freed and a low-ash coal could be obtained. However, obtaining a coal of 10 per cent ash or less would be advisable only under certain economic conditions, for a low recovery would be made and the coal would have to be crushed very fine.

Data relating to raw coal samples tested are as follows:

Coal From Mine C

Washability Curve No.	Size	Raw Coal: Ash per cent	Raw Coal: Sulphur per cent	Raw Coal: Moisture per cent	Lightest Coal: Sp. Gr.	Lightest Coal: Ash per cent (Moisture free)	Lightest Coal: Sulphur per cent (Moisture free)
		Tipple Sample P					
23	6 × 3 in.	15.1	3.25	16.5	1.241	4.05	1.60
24	3 × 1½ in.	13.9	3.34	16.5	1.242	3.36	1.96
25	1½ × ¾ in.	14.7	3.25	16.5	1.252	6.06	1.81
26	¾ × ⅜ in.	13.8	2.92	16.5	1.275	8.76	1.59
27	⅜ × 3/16 in.	14.8	2.58	16.5	1.279	7.93	1.69
28	3/16 in. × 10 mesh	15.5	2.52	16.5	1.290	7.37	1.54
29	10 × 20 mesh	13.9	2.68	16.5	.....	....	....
30	20 × 48 mesh	15.9	2.92	16.5	.....	....	....
31	48 × 0 mesh	18.8	3.84	16.5	.....	....	....
		Tipple Sample P, 6-in. Lump, Crushed with Rolls Set at ¾ in.					
32	+ 1 in.	12.6	2.80	16.5	.....	....	....
33	1 × ⅜ in.	12.3	2.75	16.5	.....	....	....
34	⅜ × 3/16 in.	10.4	3.17	16.5	.....	....	....
35	3/16 × 0 in.	14.9	3.14	16.5	.....	....	....

Table 18 gives theoretical yield values for certain selected separations. Table 19 is compiled from the theoretical yields and the lump

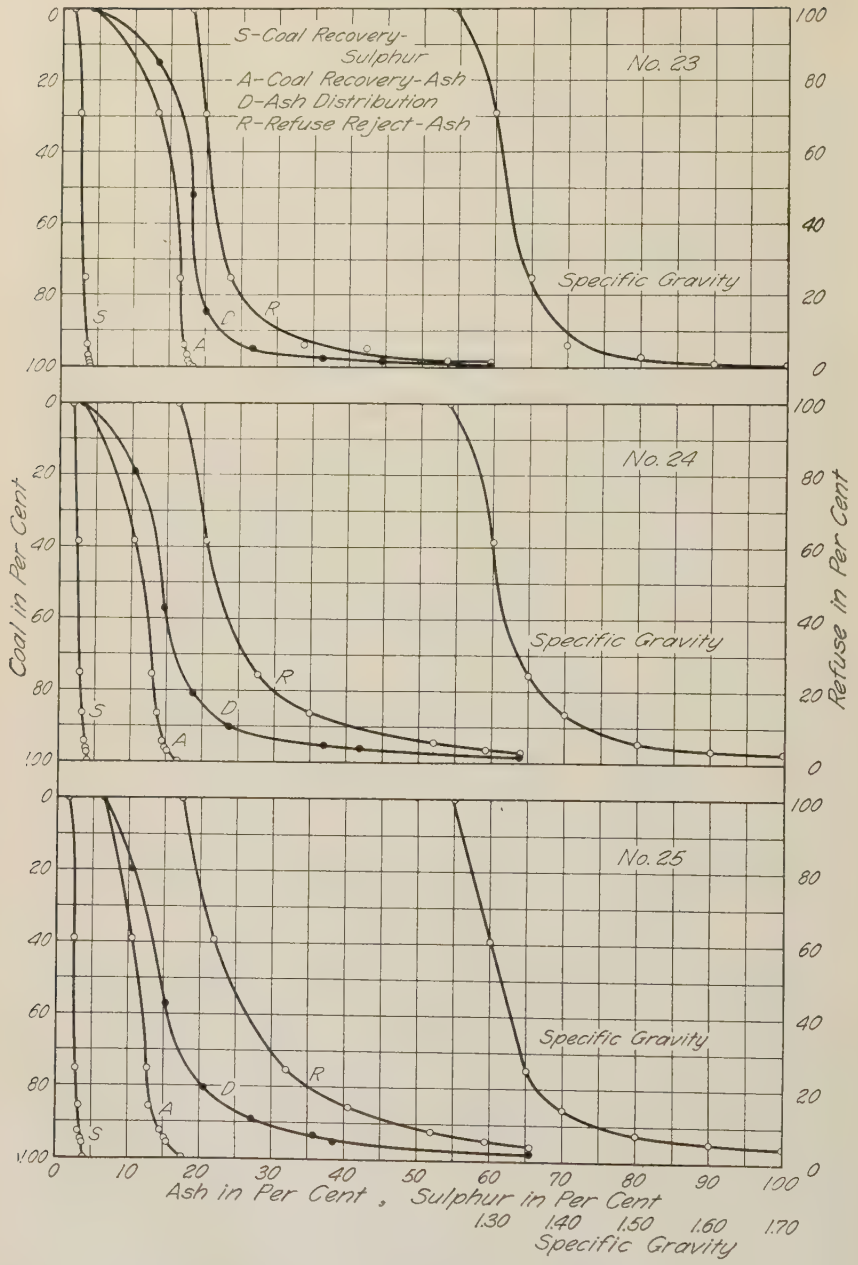

FIG. 9. WASHABILITY CURVES, MINE C, TIPPLE SAMPLE P

(Moisture Free)

Coal sizes: No. 23, 6 x 3 in.; No. 24, 3 x 1½ in.; No. 25, 1½ x ¾ in.

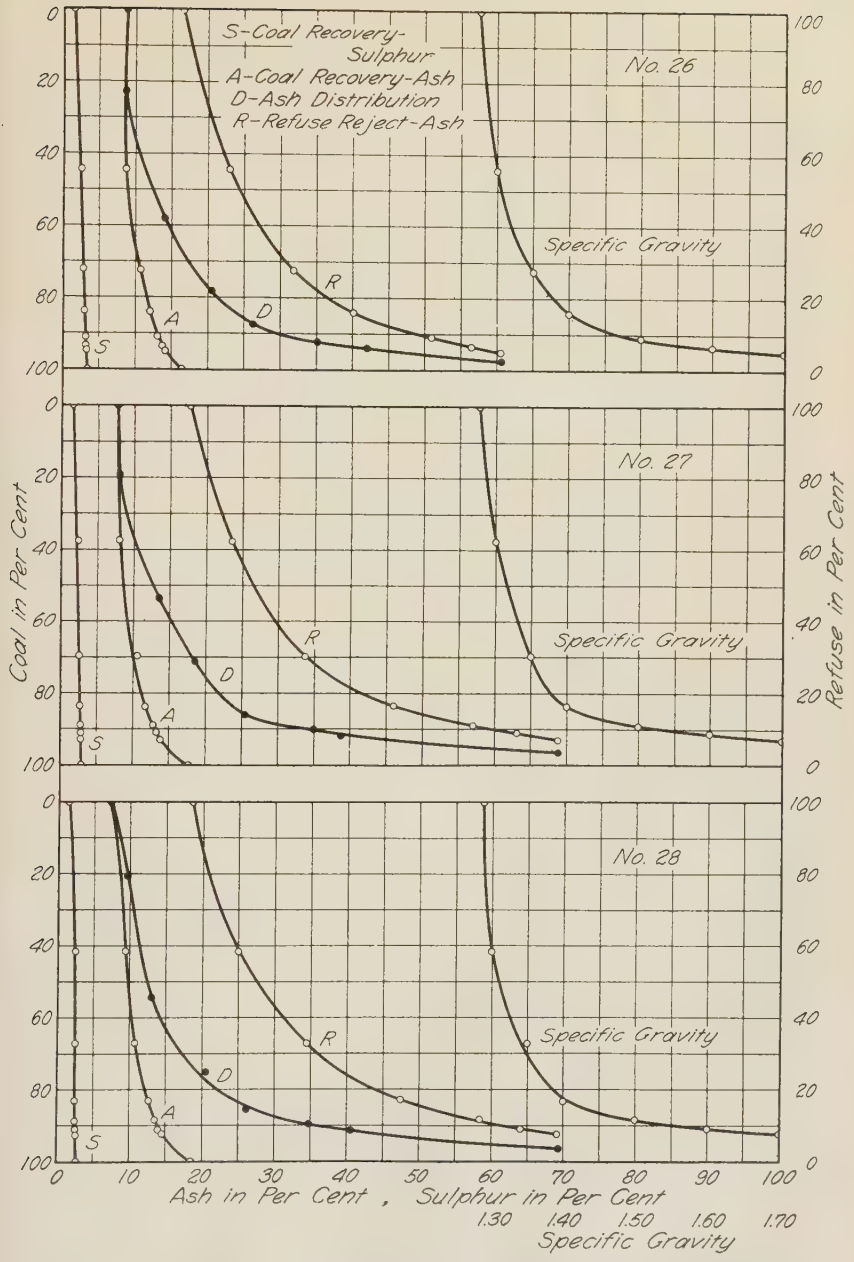

FIG. 9 (CONTINUED). WASHABILITY CURVES, MINE C, TIPPLE SAMPLE P

(Moisture Free)

Coal sizes: No. 26, ¾ x ⅜ in.; No. 27, ⅜ x 3/16 in.; No. 28, 3/16 in. x 10 mesh.

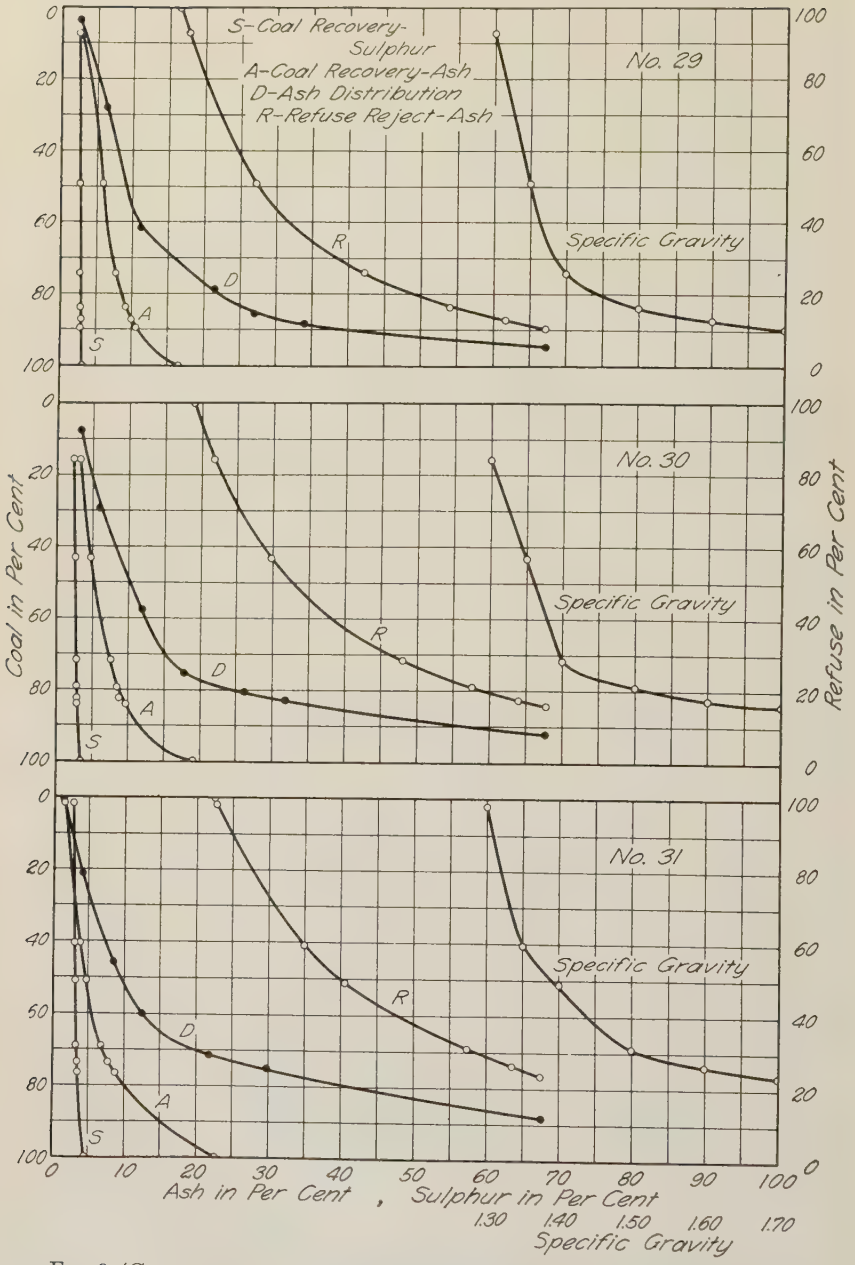

FIG. 9 (CONCLUDED). WASHABILITY CURVES, MINE C, TIPPLE SAMPLE P

(Moisture Free)

Coal sizes: No. 29, 10 x 20 mesh; No. 30, 20 x 48 mesh; No. 31, 48 x 0 mesh.

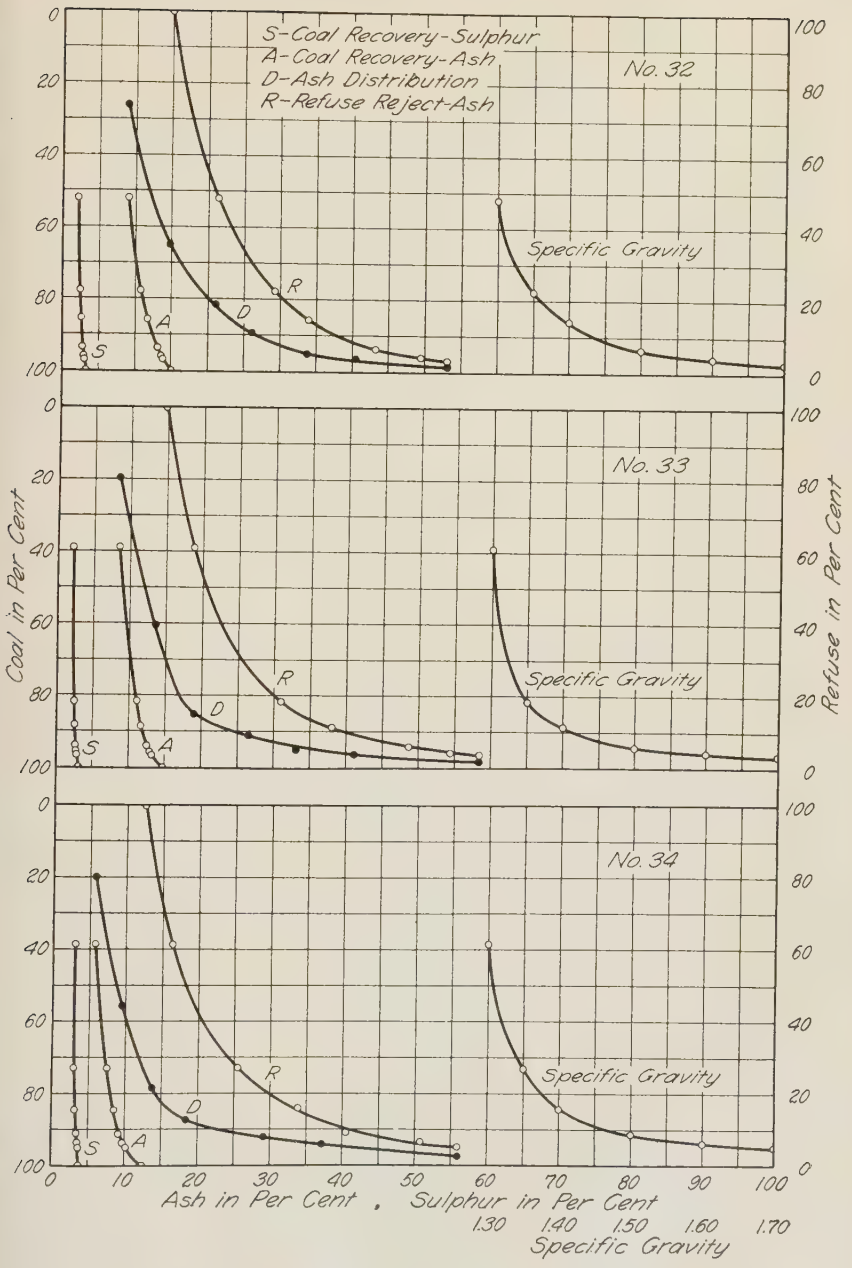

FIG. 10. WASHABILITY CURVES, MINE C, TIPPLE SAMPLE P, CRUSHED 6-IN. LUMP

(Moisture Free)

Coal sizes: No. 32, + 1 in.; No. 33, 1 x 3/8 in.; No. 34, 3/8 x 3/16 in.

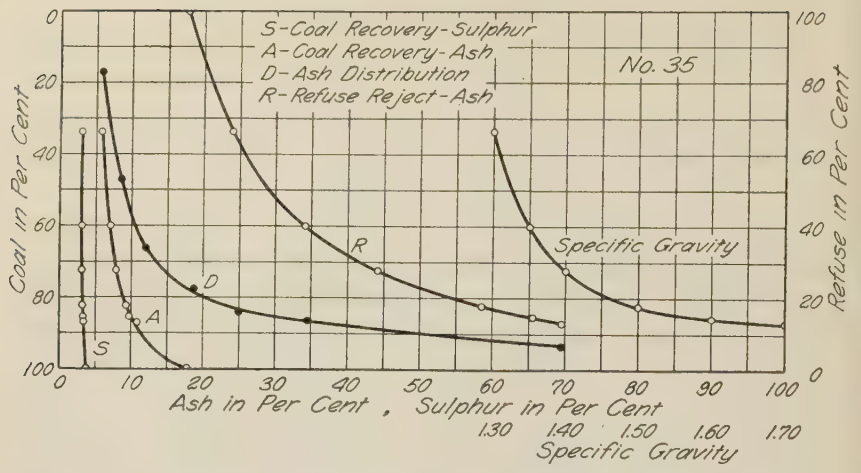

FIG. 10 (CONCLUDED). WASHABILITY CURVES, MINE C, TIPPLE SAMPLE P, CRUSHED 6-IN. LUMP

(Moisture Free)

Coal sizes: No. 35, 3/16 x 0 in.

analyses. Although these tables were compiled for a high yield, yet there is a considerable increase in the calorific value of the coal.

Table 20 gives some interesting information on the various sulphur forms and their distribution in various float-and-sink fractions. As in other coal tested, there is a concentration of sulphate and pyritic sulphur in the heavier fractions of all sizes. Offsetting this is a concentration of organic sulphur in the lighter fractions. This makes it very difficult to remove much sulphur by any cleaning process, certainly not over 25 or 30 per cent of the total.

There is not much difference between the fusibility of the coal ash of the different fractions of the size tested, there being remarkably little variation not only among the fractions but also in the samples of clean coal and refuse.

Conclusions

This is a very difficult coal to treat to get any marked reduction in ash in any but the finer sizes. The sulphur reduction would also be small, not over 25 or 30 per cent of the total sulphur present in any size treated.

17. *Mine D, Coal No. 5, Peoria County.*—This mine is a small stripping mine in the same bed of coal as Mine C. One mine sample

TABLE 17

SUMMARY OF FLOAT-AND-SINK RESULTS—MINE C

Per cent by weight and per cent ash and sulphur in fractions at different specific gravities
(moisture free)

Size	Per cent of Sample	<1.30 Sp. Gr.			1.30–1.35 Sp. Gr.			1.35–1.40 Sp. Gr.			1.40–1.50 Sp. Gr.			1.50–1.60 Sp. Gr.			1.60–1.70 Sp. Gr.			>1.70 Sp. Gr.			Total		
		Wt.	Ash	S	Wt.	Ash	S	Wt.	Ash	S	Wt.	Ash	S	Wt.	Ash	S	Wt.	Ash	S	Wt.	Ash	S	Wt.	Ash	S
6 x 3 in.	15.8	28.8	13.60	2.70	46.1	18.00	3.39	19.1	20.20	5.38	3.3	26.60	6.74	1.7	36.30	9.28	0.4	44.60	9.65	0.6	59.50	11.20	100	18.10	3.87
3 x 1½ in.	24.0	38.7	10.55	2.75	36.8	14.85	3.42	10.8	18.75	5.25	8.3	23.90	6.58	1.7	37.00	9.75	0.8	42.00	11.00	2.9	64.00	10.55	100	16.65	4.00
1½ x ¾ in.	19.5	38.8	10.45	2.44	36.3	15.15	3.32	10.6	20.69	5.16	6.6	27.14	5.73	2.4	35.70	9.30	1.2	38.48	9.48	4.1	65.60	11.16	100	16.58	3.87
¾ x ⅜ in.	15.9	44.3	8.59	2.57	27.8	14.09	3.27	11.9	20.68	4.15	7.0	26.36	5.10	2.3	35.24	5.31	1.4	42.11	5.69	5.3	60.40	6.98	100	16.63	3.47
⅜ x ³⁄₁₆ in.	5.8	37.7	8.16	2.39	31.7	13.60	2.73	13.7	18.65	3.69	5.9	25.60	4.04	2.2	35.00	4.10	1.6	38.70	4.34	7.2	68.80	5.35	100	17.74	3.05
³⁄₁₆ in. x 10 mesh	9.7	41.5	9.45	2.42	25.6	13.15	2.71	15.8	20.40	3.03	5.8	26.20	3.21	2.3	34.90	3.71	1.6	40.60	4.32	7.4	69.20	5.91	100	18.60	2.95
10 x 20 mesh	3.5	6.8	2.57	2.40	42 4	6.38	2.70	24.8	11.35	2.94	9.5	21.60	3.22	3.7	27.10	3.57	2.1	34.20	4.44	10.7	67.30	5.96	100	16.67	3.21
20 x 48 mesh	3.4	15.7	3.23	2.33	27.6	5.70	2.90	28.6	12.00	3.04	6.9	17.90	3.19	3.5	26.20	3.93	1.8	31.90	4.85	15.9	67.80	6.19	100	19.03	3.47
48 x 0 mesh	2.4	1.6	1.52	2.74	38.8	4.04	3.14	10.4	8.51	3.45	18.4	12 58	3.92	4 6	21.78	4.24	2.6	29.87	4.43	23.6	67.40	8.37	100	22.47	4.63
6 x 0 mesh	100.0	35.5	10.10	2.79	35.3	15.90	3.26	14.0	18.72	4.57	6 8	32.50	5.30	2.2	32.80	6.80	1.1	40.00	7.27	5.1	65.00	7.64	100	18.52	3.77
6-in. Lump	24.0																						100	15.11	3.45
6 x 0 in.	76.0																						100	18.52	3.77
Total R. O. M.	100																						100	17.70	3.69

TABLE 18

THEORETICAL YIELDS—MINE C

(6 x 0-in. Coal—Moisture Free)

Size	Per cent of Total	Raw Coal		Yield per cent		Separation at Sp. Gr.	Coal		Refuse	
		Ash per cent	S per cent	Coal	Refuse		Ash	S	Ash	S
6 x 3 in.	15.8	18.1	3.9	94.0	6.0	1.40	17.0	3.6	33.7	8.1
3 x 1½ in.	24.8	16.7	4.0	86.3	13.7	1.40	13.8	3.4	35.0	8.1
1½ x ¾ in.	19.5	17.6	3.9	85.7	14.3	1.40	13.1	3.2	40.5	8.2
¾ x ⅜ in.	15.9	16.6	3.5	84.0	16.0	1.40	12.1	3.0	40.3	5.8
⅜ x 3/16 in.	5.8	17.7	3.1	92.8	7.2	1.70	13.8	2.9	68.8	5.4
3/16 in. x 10 mesh.	9.7	18.6	3.0	92.6	7.4	1.70	14.6	2.7	69.2	5.6
10 x 20 mesh	3.5	16.7	3.2	89.3	10.7	1.70	10.6	2.9	67.3	6.0
20 x 48 mesh	3.4	19.0	3.5	84.1	15.9	1.70	9.8	3.0	67.8	6.2
48 x 0 mesh	2.4	22.5	4.6	76.4	23.6	1.70	8.8	3.5	67.4	8.4

was taken with the increment samples as given in Fig. 11. The coal is very similar in appearance to the Mine C coal. It is very hard, resists weathering exceptionally well and breaks in large rectangular slabs along the bedding planes.

The impurities noted were similar to those noted at Mine C and seem to be characteristic of this bed. Thin bands of shale, pyrite, bony coal, and mineral charcoal predominate. A few small veinlets and stringers of pyrite were present. In general, the greater percentage of impurities was found along bedding planes and varied from a streak to lenses of 2 inches or more in thickness.

Since this was a small operation only one channel sample and one set of increment samples were taken for analysis. The coal bed moisture as given by these samples was high, averaging 16.6 per cent.

The average calorific value of this coal is 10 000 B.t.u. The softening point of the coal ash varies from 1956 to 2120 deg. F. which puts it in Class 3.

The organic sulphur is equal to about 50 per cent of the total sulphur and is remarkably regular for all increment samples. The variation in organic sulphur is only 0.3 per cent in all the samples analyzed.

18. *Mine E, Coal No. 2, LaSalle County.*—The coal substance is fairly hard and is made up of fine bands of alternating bright and dark coal layers in the proportion of about 50 per cent of each. These bands are thin and very regular. There is little cleat although enough to influence the breaking of the lumps into large cubical pieces. The

TABLE 19

YIELDS FROM 1000 TONS OF RUN-OF-MINE COAL—MINE C

Coal, Not Cleaned						Coal, Cleaned						Total Coal Yield per cent	Refuse	
Size	Tons	M*	Ash	S	B.t.u.	Size	Tons	M*	Ash	S	B.t.u.		Tons	Per Cent
6-in. Lump.....	240	16.5	12.5	2.9	10 120	6 x 0 in.	670	16.5	10.1	2.7	10 590	91.0	90	9.0
3-in. Lump.....	360	16.5	13.4	3.0	9 980	3 x 0 in.	560	16.5	10.8	2.6	10 380	92.0	80	8.0
3-in. Lump.....	360	16.5	13.4	3.0	9 980	3 x ⅜ in.	400	16.5	10.9	2.7	10 380	92.0	80	8.0
						⅜ x 0 in.	160	16.5	10.6	2.4	10 460			

*The analyses are for a moisture content of 16.5 per cent, the average moisture in the coal as mined. The moisture in the cleaned coal will depend upon the method of cleaning used.

TABLE 20

SULPHUR DISTRIBUTION AND SOFTENING TEMPERATURE OF ASH OF SELECTED FLOAT-AND-SINK FRACTIONS—MINE C

(Moisture Free)

Size	Fractions	Sulphate Sulphur	Pyritic Sulphur	Organic Sulphur	Total Sulphur	Softening Temperature of Ash deg. F.
3 x 1½ in.	1.30 Float	0.07	0.61	2.07	2.75	
	1.30–1.35 Float	0.05	1.20	2.22	3.42	
	1.35–1.40 Float	0.07	3.02	2.16	5.25	
	1.40–1.50 Float	0.40	4.58	1.60	6.58	
	1.50–1.60 Float	0.44	7.64	1.71	9.75	
	1.60–1.70 Float	0.34	8.36	2.30	11.00	
	1.70 Sink	0.84	9.25	0.46	10.55	
1½ x ¾ in.	1.30 Float					1932
	1.30–1.35 Float					1920
	1.35–1.40 Float					2050
	1.40–1.50 Float					2000
	1.50–1.60 Float					2040
	1.60–1.70 Float					2234
	1.70 Sink					2040
¾ x ⅜ in.	1.30 Float	0.03	0.59	1.95	2.57	
	1.30–1.35 Float	0.03	0.95	2.29	3.27	
	1.35–1.40 Float	0.08	1.84	2.23	4.15	
	1.40–1.50 Float	0.11	2.90	2.09	5.10	
	1.50–1.60 Float	0.15	3.88	1.28	5.31	
	1.60–1.70 Float	0.15	3.47	2.07	5.69	
	1.70 Sink	0.18	6.00	0.80	6.98	
10 x 20 mesh	1.30 Float	0.04	0.38	1.98	2.40	
	1.30–1.35 Float	0.04	0.50	2.16	2.70	
	1.35–1.40 Float	0.07	0.71	2.16	2.94	
	1.40–1.50 Float	0.24	1.35	1.63	3.22	
	1.50–1.60 Float	0.29	1.83	1.45	3.57	
	1.60–1.70 Float	0.24	2.25	1.95	4.44	
	1.70 Sink	0.46	4.25	1.25	5.96	
1½ x ¾ in.	1.50 Float					1956
	1.50 Sink					2000

bed varies in thickness from 30 to 48 inches and averages about 42 inches.

Impurities

The chief impurity seems to be bands of mineral charcoal along the bedding planes varying from a streak to lenses two inches or more in thickness. An occasional pyrite and bony coal band is found. None of these bands are persistent and they only occur for short intervals. There is little evidence of pyrite or clay veins. Some flake pyrite is found in the vertical cleavage planes. Some calcite and gypsum were noticed as flakes in vertical cleavage planes.

The roof overlying the coal is of soapstone which tends to break rather easily. A considerable percentage of this fine soapstone gets mixed with the coal during mining operations.

The floor is generally of a soft to medium hard clay. At times

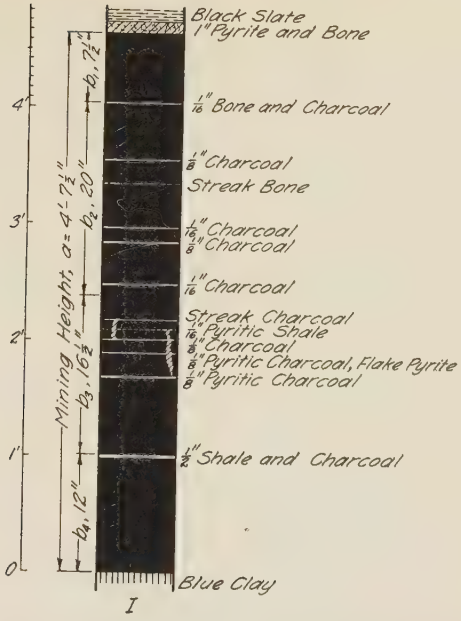

FIG. 11. FACE SECTIONS OF NO. 5 COAL, PEORIA COUNTY, MINE D

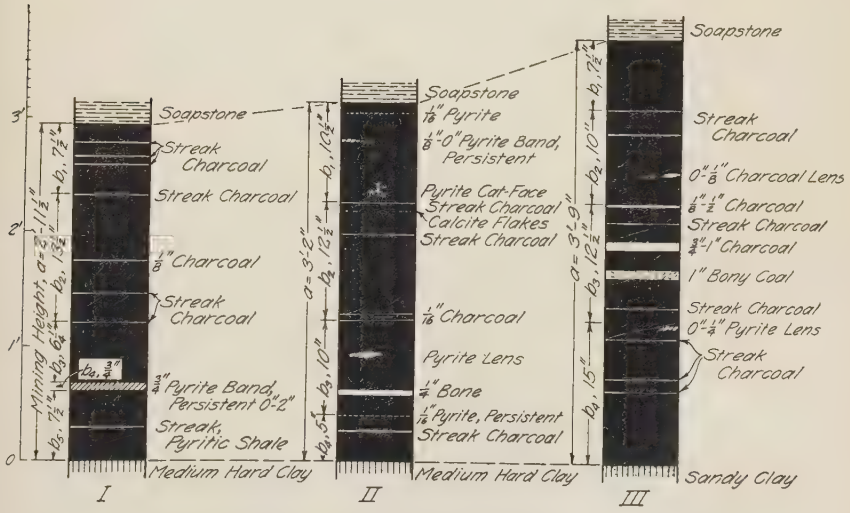

FIG. 12. FACE SECTIONS OF NO. 2 COAL, LASALLE COUNTY, MINE E

TABLE 21

ANALYSES OF MINE SAMPLES—MINE D

As Received

Sample Number	Moisture	V. M.	F. C.	Ash	Total Sulphur	Sulphate Sulphur	Pyritic Sulphur	Organic Sulphur	Calculated B.t.u.	Softening Temperature of Ash deg. F.
DIa	17.89	35.46	34.87	11.78	2.52	0.17	0.82	1.53	9 800	2110
DIb1	13.48	36.89	37.78	11.85	2.39	0.18	0.73	1.48	10 490	1956
DIb2	14.77	39.92	35.18	10.13	2.99	0.04	1.30	1.65	10 640	2120
DIb3	14.80	40.41	31.31	13.48	2.59	0.27	1.10	1.22	10 080	2020
DIb4	22.08	36.83	28.35	12.74	1.88	0.04	0.41	1.43	8 990	2055

Suffix a indicates a complete channel sample.
Suffix b indicates increment samples; see Fig. 11.

Table 22

Analyses of Mine Samples—Mine E

As Received

Sample Number	Moisture	V. M.	F. C.	Ash	Total Sulphur	Sulphate Sulphur	Pyritic Sulphur	Organic Sulphur	Calculated B.t.u.	Softening Temperature of Ash deg. F.
EIa	11.99	37.82	38.81	11.38	4.25	0.08	2.45	1.72	11 080*	1968
EIIa	10.90	39.52	40.30	9.21	3.31	0.06	2.02	1.23	11 540*	1950
EIIIa	15.71	37.20	39.61	7.47	3.15	0.04	1.52	1.59	11 150*	2225
EIb1	11.25	42.16	41.04	5.55	3.01	0.04	0.63	2.34	12 090	1991
EIb2	11.79	40.65	41.97	5.60	2.52	0.02	0.61	1.89	11 960	1956
EIb3	11.88	40.12	37.94	9.06	2.51	0.03	0.82	1.66	11 440	2180
EIb4	4.70	25.43	20.85	49.02	31.78	0.33	30.39	1.06	5 230	2618
EIb5	12.22	38.42	37.41	11.95	3.00	0.04	1.09	1.87	10 900	1835
EIIb1	14.05	35.03	35.05	15.87	7.57	0.09	5.51	1.97	10 030	2030
EIIb2	12.46	39.43	39.49	9.62	3.44	0.04	1.68	1.72	11 260	1816
EIIb3	13.71	36.62	38.21	11.46	3.24	0.04	1.50	1.70	10 780	2010
EIIb4	13.11	38.41	41.11	8.36	3.00	0.04	1.43	1.53	11 390	2135
EIIIb1	12.54	38.37	41.32	7.78	3.83	0.07	2.00	1.76	11 550	2270
EIIIb2	13.29	41.97	38.20	6.53	2.82	0.04	1.06	1.72	11 660	2252
EIIIb3	14.93	38.38	38.37	8.31	3.50	0.04	1.74	1.74	11 000	2294
EIIIb4	14.56	37.77	38.79	8.89	3.25	0.05	1.84	1.36	11 080	2170

*Calorimeter determinations.
Suffix a indicates a complete channel sample.
Suffix b indicates increment samples; see Fig. 12

this clay is sandy and occasionally "sand rock" replaces it directly under the coal. Undercutting is done in the clay where it is present and some of this clay gets mixed with the coal.

Mine Samples

The mine was sampled at three places. The two on the south side, where Samples I and II were taken, were somewhat disturbed by local rolls and small slip faults. The third sample was taken in the northwestern part of the mine from which most of the output is derived. Figure 12 illustrates graphically the condition of the bed where the face samples were taken. Table 22 gives the analyses of these mine samples, and the exact location of the increment samples in the bed can be determined by referring to Fig. 12.

The average mine moisture is 12.4 per cent, which is about 2 per cent lower than generally expected for this field. The calorific value of the coal as mined will average better than 11 000 B.t.u. The softening temperature of the coal ash varies from 1900 to 2200 deg. F., and this ash would therefore be classed as a low-fusing ash or as Class 3.

There is a considerable variation in the ash percentage although the coal is fairly uniform from top to bottom except where impurities abnormally increase the percentage of ash. There is no particular bench of coal that is any better than any other bench over any considerable area.

The sulphur in this coal is fairly high, with the organic sulphur comprising about 50 per cent of the total. There is very little variation in organic sulphur percentages from top to bottom of the bed.

Tipple Sample

All coal at this mine is passed through a single-roll crusher set at approximately 5 inches. From the crusher it passes over a bar screen with the bars spaced about 1¼ inches apart. There were 1100 pounds of the bar screen oversize and 900 pounds of the undersize taken for treatment in the laboratory. The ratio of the weights of these samples (1100:900) was the exact ratio of oversize to screenings produced at this mine.

Test Procedure and Washability Analyses

The coal from this mine was screened into the sizes given in Table 23. All sizes are exact screen sizes except the 5 x 3-in. coal. This is the coal that remained on a 3-in. round hole screen after being passed through a single roll crusher set at approximately 5 inches. The

TABLE 23

SCREEN ANALYSIS—MINE E

Sample P

Size	Weight per cent	Cumulative Weight per cent	Ash per cent (Moisture Free)	Sulphur per cent (Moisture Free)
5 x 3 in.*	24.2	24.2	13.50	6.42
3 x 1½ in.	25.8	50.0	12.71	5.97
1½ x ¾ in.	21.8	71.8	16.22	4.96
¾ x ⅜ in.	15.5	87.3	16.45	5.11
⅜ x 3/16 in.	5.9	93.2	15.76	4.70
3/16 in. x 10 mesh	2.6	95.8	19.10	4.25
10 x 20 mesh	1.9	97.7	21.60	4.64
20 x 48 mesh	1.4	99.1	28.84	5.02
48 x 100 mesh	0.4	99.5	31.17	5.24
100 x 200 mesh	0.2	99.7	43.38	5.07
200 x 0 mesh	0.3	100.0	36.06	6.68
Totals and averages	100.0		15.24	5.57

*Coal that passes through a crusher set at 5 inches and over a 3-inch round hole screen.

upper limit therefore is not an exact screen size but rather a crusher size. This coal is then crusher size 5 inches by screen size 3 inches.

It is to be noticed that the average ash of the sample taken for washability studies is considerably higher than the average ash analyses for the mine samples. This is due to the inclusion of foreign material from the roof and floor during mining operations. Since most of this material is fine, it shows up in the size below 1 inch. This coal has the characteristic ash segregation or concentration in the finer sizes typical of all the coals tested.

There is very little variation of sulphur percentage in the various sizes. There is a slight concentration of sulphur in the larger sizes. The dust (200 x 0 mesh) also has a slight concentration of sulphur.

That this coal resists breakage very well is evident from the screen analyses. Even after being passed through a crusher over 93 per cent of the coal is above 3/16 of an inch.

All of the sizes listed in Table 23 were subjected to float-and-sink analyses, the larger sizes in their entirety and the smaller sizes quartered down to a suitable sample for ease in handling, although the three finest sizes were combined and run as a composite or 48 x 0 mesh.

Table 24 and washability curves 36 to 44, inclusive, Fig. 13, give the results of the float-and-sink analyses of this coal. These curves

Table 24

Summary of Float-and-Sink Results—Mine E

Per cent by weight and per cent ash and sulphur in fractions at different specific gravities
(moisture free)

Size	Per cent of Sample	<1.30 Sp. Gr.			1.30–1.35 Sp. Gr.			1.35–1.40 Sp. Gr.			1.40–1.50 Sp. Gr.			1.50–1.60 Sp. Gr.			1.60–1.70 Sp. Gr.			>1.70 Sp. Gr.			Total		
		Wt.	Ash	S	Wt.	Ash	S	Wt.	Ash	S	Wt.	Ash	S	Wt.	Ash	S	Wt.	Ash	S	Wt.	Ash	S	Wt.	Ash	S
5 x 3 in.*.....	24.2	47.3	6.90	3.71	26.5	11.35	4.69	7.7	16.28	6.23	6.9	24.05	9.48	1.7	29.50	12.71	3.5	31.94	16.94	6.4	42.15	23.10	100	13.50	6.42
3 x 1½ in.....	25.8	66.5	7.10	3.61	17.3	11.17	4.93	2.9	20.01	6.84	3.1	20.28	7.30	1.5	23.94	10.26	1.2	34.70	14.82	7.5	54.40	26.14	100	12.71	5.97
1½ x ¾ in.....	21.8	42.3	5.22	2.90	26.0	12.44	4.09	16.0	17.94	6.18	3.5	26.81	8.33	2.7	35.13	9.96	1.1	35.12	10.44	8.4	67.00	12.00	100	16.22	4.96
¾ x ⅜ in.....	15.5	61.6	8.23	3.77	18.9	10.75	4.52	3.7	17.80	5.86	3.1	24.69	7.06	1.5	31.13	8.35	1.2	37.75	9.72	10.0	70.24	12.57	100	16.45	5.11
⅜ x 3/16 in.....	5.9	67.2	4.44	3.50	6.4	9.15	4.41	4.4	17.14	4.91	4.5	17.21	6.24	2.0	25.67	7.71	1.0	31.95	8.07	14.7	67.00	9.10	100	15.76	4.70
3/16 in. x 10 mesh	2.6	64.7	6.58	2.48	5.7	9.34	4.33	4.3	11.06	4.46	5.6	16.02	5.97	1.3	23.84	7.28	1.3	30.40	8.64	17.4	70.90	9.65	100	19.10	4.25
10 x 20 mesh...	1.9	49.6	3.51	1.09	13.5	8.39	3.74	6.0	10.60	3.83	5.4	14.60	4 03	1.7	22.98	7.80	1 5	29.13	8.77	22.3	74.38	12 94	100	21.60	4.64
20 x 48 mesh...	1.4	23.7	2.99	1.93	25.2	4.42	2 26	9.7	8.58	3.70	7.0	13.31	5.58	2.4	19.90	7.41	1 2	26.73	7.48	30.9	79.20	9.66	100	28.84	5.02
48 x 0 mesh....	0.9	8.4	2.92	2.71	16.6	4.02	3.01	10.2	7.75	3.69	8.5	11.70	3.77	5.1	15.30	4.65	6.5	18.40	4.93	44.7	79.70	9.34	100	40.30	6.18
5 x 0 in.....	100.0	54.3	6.63	3.46	20.7	11.25	4.49	7.3	17.20	5.88	4.4	24.80	7.96	1.9	29.20	10.55	1.8	32.90	13.34	9.4	62.30	16.27	100	15.24	5.57

*Coal that passed through a crusher set at 5 inches and over a 3-inch round hole screen.

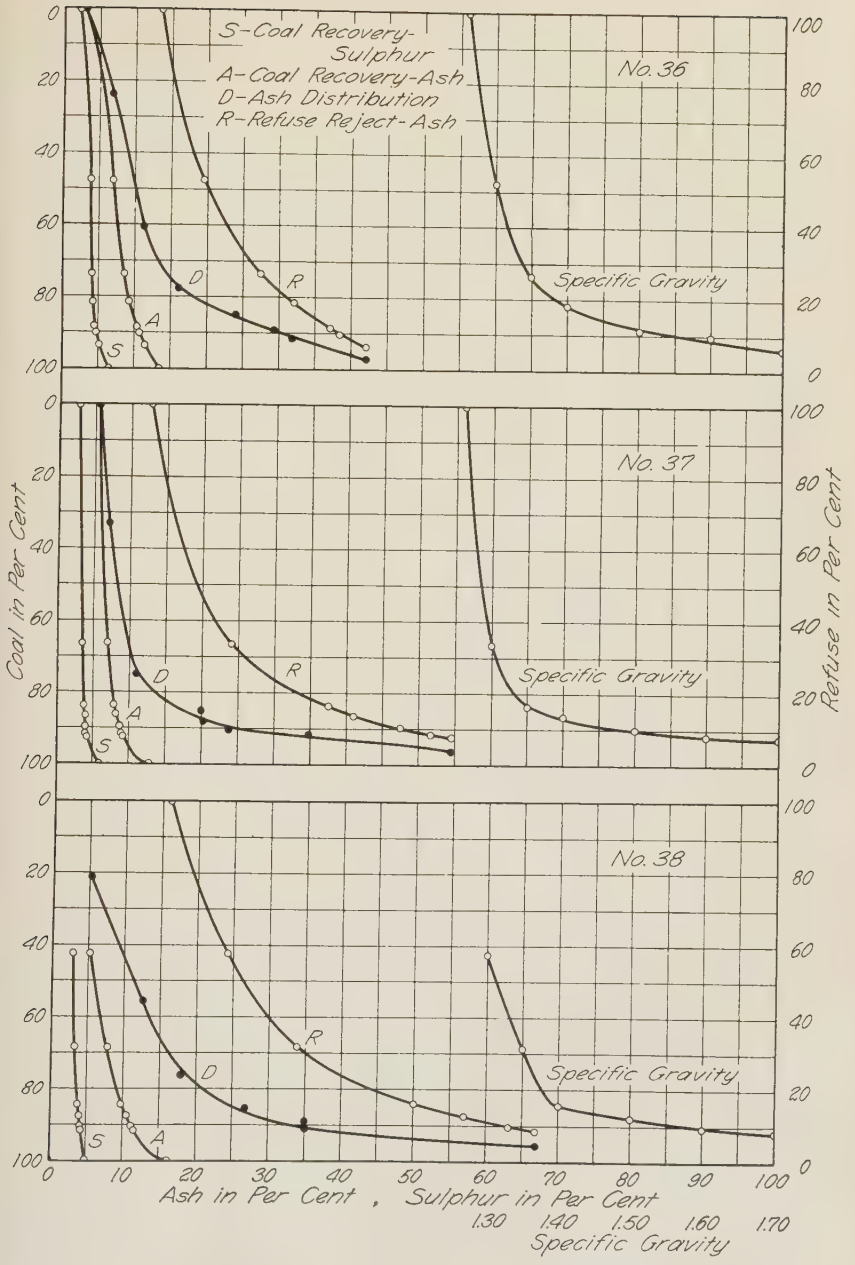

FIG. 13. WASHABILITY CURVES, MINE E, TIPPLE SAMPLE P

(Moisture Free)

Coal sizes: No. 36, 5 x 3 in.; No. 37, 3 x 1½ in.; No. 38, 1½ x ¾ in.

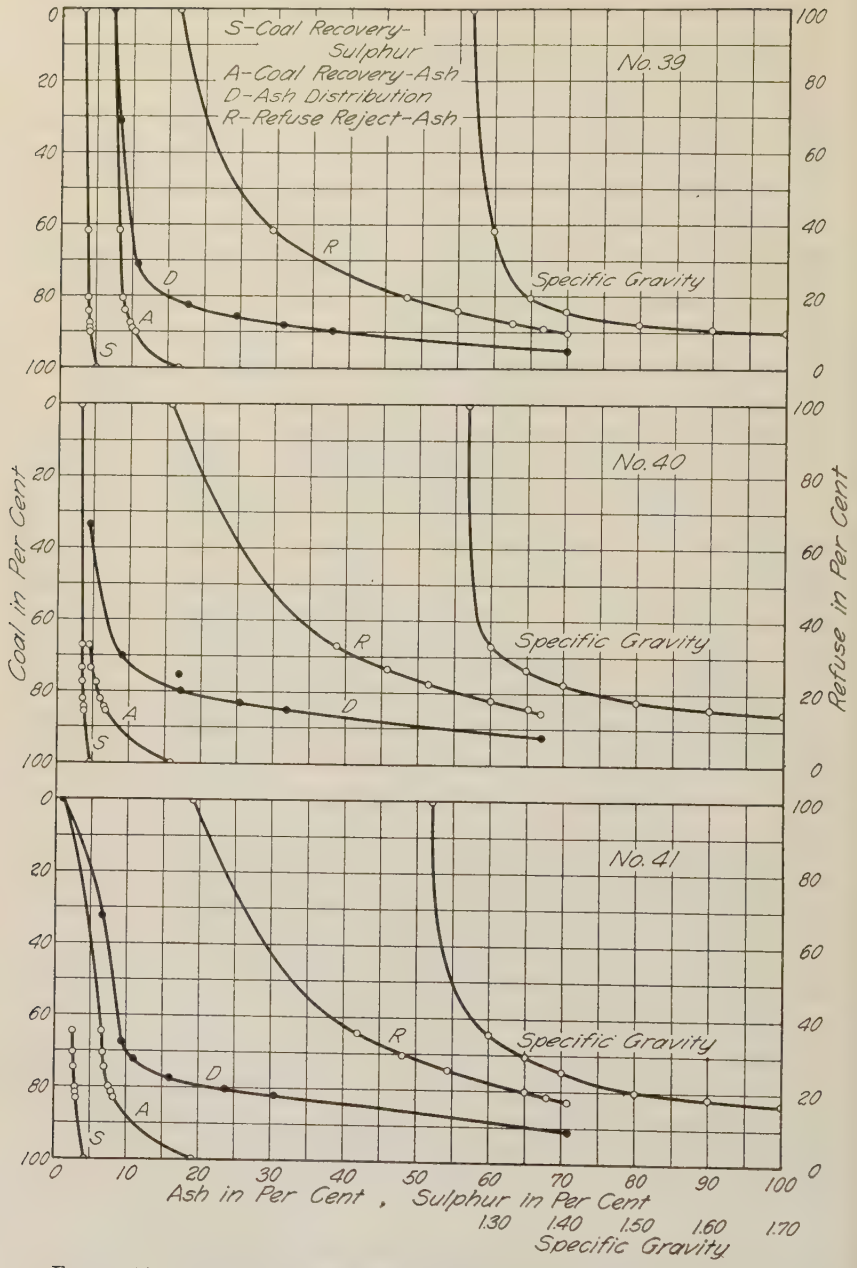

FIG. 13 (CONTINUED). WASHABILITY CURVES, MINE E, TIPPLE SAMPLE P

(Moisture Free)

Coal sizes: No. 39, ¾ x ⅜ in.; No. 40, ⅜ x 3/16 in.; No. 41, 3/16 in. x 10 mesh.

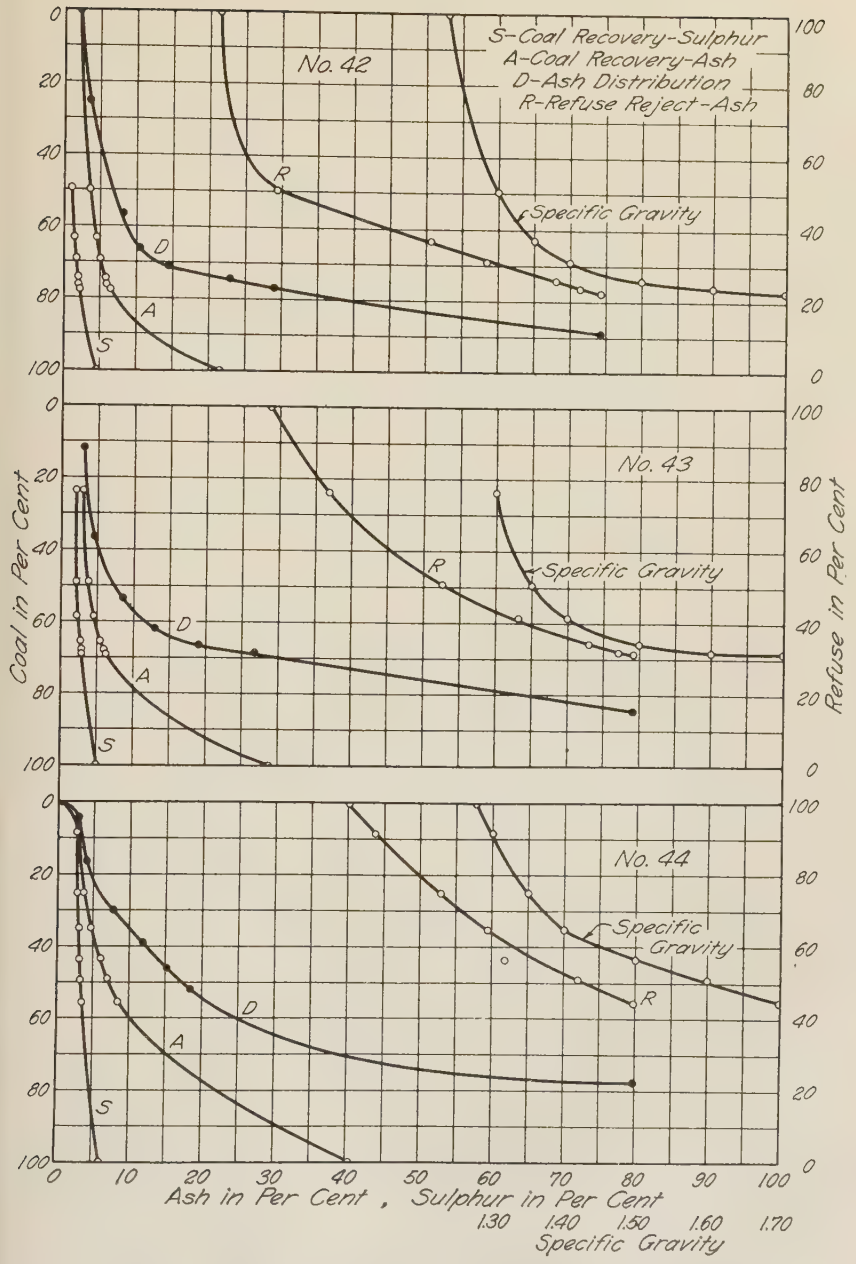

FIG. 13 (CONCLUDED). WASHABILITY CURVES, MINE E, TIPPLE SAMPLE P

(Moisture Free)

Coal sizes: No. 42, 10 x 20 mesh; No. 43, 20 x 48 mesh; No. 44, 48 x 0 mesh.

TABLE 25

THEORETICAL YIELDS—MINE E

(Moisture Free)

Size	Per cent of Total	Raw Coal		Yield per cent		Separation at Sp. Gr.	Coal		Refuse	
		Ash per cent	S per cent	Coal	Refuse		Ash	S	Ash	S
5 x 3 in.	24.2	13.50	6.42	90.1	9.9	1.60	10.8	4.8	38.6	20.9
3 x 1½ in.	25.8	12.71	5.97	91.3	8.7	1.60	9.0	4.2	51.7	24.6
1½ x ¾ in.	21.8	16.22	4.96	90.5	9.5	1.60	11.3	4.2	63.3	11.7
¾ x ⅜ in.	15.5	16.45	5.11	90.0	10.0	1.70	10.5	4.3	70.2	12.6
⅜ x 3/16 in.	5.9	15.76	4.70	85.3	14.7	1.70	6.9	3.9	67.0	9.1
3/16 in. x 10 mesh	2.6	19.10	4.25	82.7	17.3	1.70	8.3	3.1	70.9	9.7
10 x 20 mesh	1.9	21.60	4.64	77.7	22.3	1.70	6.5	2.3	74.4	12.9
20 x 48 mesh	1.4	28.84	5.02	69.1	30.9	1.70	6.3	2.9	79.2	9.7
48 x 0 mesh	0.9	40.30	6.18	55.3	44.6	1.70	8.5	3.6	79.9	9.3

show fairly sharp breaks in the A, D, and S.G. curves, as well as the D curve flattening out in the lower portion, all of which indicate that this coal can be cleaned to any predetermined ash content that can be justified by an economic study of the curves. The breaks in the curves are more pronounced for the sizes below ¾ inch. The ¾ x ⅜-in. size shows a reduction of about 9 per cent in the ash percentage by cleaning at 1.70 specific gravity, giving a coal of 6.9 per cent ash at 86 per cent recovery. The refuse would have an ash content of 67 per cent, a refuse with little or no fuel value. The sizes above this size do not respond quite as well, while the sizes below are equally amenable to treatment.

The sulphur reduction is relatively low in most sizes as could be predicted from the analyses of the mine samples. Table 25, giving theoretical yields for arbitrarily selected specific gravities, shows that the reduction in sulphur percentage varies from 1 to as high as 2.5 per cent in the finest size.

Data relating to raw coal samples tested are as follows:

COAL FROM MINE E, TIPPLE SAMPLE P

Washability Curve No.	Raw Coal				Lightest Coal		
	Size	Ash per cent	Sulphur per cent	Moisture per cent	Sp. Gr.	Ash per cent (Moisture free)	Sulphur per cent (Moisture free)
36	5 × 3 in.	11.8	5.60	12.4	1.262	2.95	2.33
37	3 × 1½ in.	11.1	5.25	12.4	1.263	5.52	2.72
38	1½ × ¾ in.	14.2	4.34	12.4	.....	....	....
39	¾ × ⅜ in.	14.4	4.46	12.4	1.271	7.24	3.20
40	⅜ × 3/16 in.	13.8	4.11	12.4	1.269	....	3.25
41	3/16 in. × 10 mesh	16.7	3.72	12.4	1.222	0.96	....
42	10 × 20 mesh	18.9	4.03	12.4	1.231	2.08	....
43	20 × 48 mesh	25.2	4.39	12.4	.....	....	....
44	48 × 0 mesh	35.3	5.32	12.4	1.277	0.52	....

TABLE 26

YIELDS FROM 1000 TONS OF RUN OF MINE COAL CRUSHED TO 5 INCHES AND UNDER—MINE E

Size	Coal, Cleaned					Total Coal Yield per cent	Refuse	
	Tons	M*	Ash	S	B.t.u.		Tons	Per Cent
5 x 0 in.	892	12.4	8.8	3.8	11 370	89.2	108	10.8
5 x ⅜ in.	779	12.4	9.0	3.8	11 360	89.2	108	10.8
⅜ x 0 in.	113	12.4	6.3	3.1	11 790			

*The analyses are for a moisture content of 12.4 per cent, the average moisture in the coal as mined. The moisture in the cleaned coal will depend upon the method of cleaning used.

TABLE 27

SULPHUR DISTRIBUTION AND SOFTENING TEMPERATURE OF ASH OF SELECTED FLOAT-AND-SINK FRACTIONS—MINE E

(Moisture Free)

Size	Fractions	Sulphate Sulphur	Pyritic Sulphur	Organic Sulphur	Total Sulphur	Softening Temperature of Ash deg. F.
3 x 1½ in.	1.30 Float	0.09	1.72	1.80	3.61	
	1.30-1.35 Float	0.13	3.06	1.74	4.93	
	1.35–1.40 Float	0.30	4.25	2.29	6.84	
	1.40–1.50 Float	0.28	5.46	1.56	7.30	
	1.50–1.60 Float	0.29	7.89	2.08	10.26	
	1.60–1.70 Float	0.48	12.42	1.91	14.82	
	1.70 Sink	0.50	23.60	2.04	26.14	
1½ x ¾ in.	1.30 Float					2318
	1.30–1.35 Float					2252
	1.35–1.40 Float					2252
	1.40–1.50 Float					1944
	1.50–1.60 Float					2326
	1.60–1.70 Float					2430
	1.70 Sink					2312
¾ x ⅜ in.	1.30 Float	0.07	1.90	1.80	3.77	
	1.30–1.35 Float	0.21	4.16	0.15	4.52	
	1.35–1.40 Float	0.14	5.60	0.12	5.86	
	1.40–1.50 Float	0.16	5.48	1.42	7.06	
	1.50–1.60 Float	0.18	6.61	1.56	8.35	
	1.60–1.70 Float	0.22	8.58	0.92	9.72	
	1.70 Sink	0.23	12.32	0.02	12.57	
10 x 20 mesh	1.30 Float	0.07	0.86	0.16	1.09	
	1.30–1.35 Float	0.18	2.16	1.40	3.74	
	1.35–1.40 Float	0.21	2.71	0.91	3.83	
	1.40–1.50 Float	0.15	3.87	0.01	4.03	
	1.50–1.60 Float	0.23	5.99	1.58	7.80	
	1.60–1.70 Float	0.32	6.70	1.75	8.77	
	1.70 Sink	0.32	9.68	2.94	12.94	
1½ x ¾ in.	1.40 Float					2220
	1.40 Sink					2310

Table 26, which is compiled from Table 25, gives the total coal yield that could be expected from treating 1000 tons of this coal. The table shows that with a yield of 89 per cent, coal with an ash percentage of about 9 per cent should be expected. This would give a coal about 8 per cent lower in ash than the raw coal. Since the ash content of the refuse is high, there would be little fuel value left in it.

Table 27 gives some interesting data on the distribution of the various sulphur forms in float-and-sink fractions of certain selected sizes. It also gives the variation in fusibility of the coal ash. There is very little variation in the fusibility of the ash of the clean coal and of the refuse.

Conclusions

A clean coal of any desired ash content could be produced within the limits of the A or coal recovery curves for the various sizes. However, it would seem desirable to produce a clean coal of between 8 and 9 per cent ash for the following reasons:

(a) The recovery is high, nearly 90 per cent

(b) A clean refuse would be produced without serious loss of coal.

Very little sulphur can be removed by any cleaning process, although the removal of the heavy pyrite particles could be accomplished.

19. *Mine F, Coal No. 6, Franklin County.*—The coal is fairly hard, and has a high percentage of glance or bright coal which gives the coal an attractive bright glossy luster. The coal breaks in tabular lumps along the bedding planes sided by the vertical cleavage planes which are present to some extent. There is a considerable amount of mineral charcoal present in this bed. It is found deposited along the bedding planes in streaks that widen locally to bands and lenses several inches thick. This mineral charcoal is very friable and consequently the screenings from this mine contain a high percentage of this material.

The bed has an approximate thickness of 11 feet. About 20 inches of coal is left up for roof support and 10 inches of coal left on the floor. This leaves about 100 inches of coal that is removed by mining operations.

The blue band which is characteristic of this bed of coal varies from a streak to as high as 6 inches.

Impurities

Figure 14 gives a graphical representation of the places sampled with the location of all impurities. They are chiefly the blue band,

which is a fairly hard clay shale with streaks and lenses of bony coal and mineral charcoal. In some sections of the mine a peculiar impurity, called "black jack" by the miners, is found. It is commonly thought to be high in sulphur because the lumps of coal carrying this impurity are so heavy. It was revealed by a close examination with the microscope that these lumps of "black jack" were lumps of coal with a great number of very fine calcite veinlets. These veinlets were so small that to the naked eye the characteristic white color of calcite mineral was clouded by the surrounding coal and almost entirely absent. These veinlets are chiefly vertical, although frequently they radiate out to such an extent that portions of them appear to have been deposited horizontally. The high ash content of increment sample IIb1 is due to the fact that very fine stringers of "black jack" cut across this sample.

Mine Samples

The mine is worked in all directions from the shaft bottom and the places sampled were located in the north, east, west, and south. Four complete channel samples and increment samples of the working height of the bed were taken as shown in Fig. 14. Since top and bottom coal is left during mining operations only the part of the bed as mined was sampled except in the case of face section IV. At this place a sample of the top coal was taken by drilling through it with a breast auger. The bottom coal was sampled by digging through it with a pick.

Table 28 gives the analyses of these various samples. These analyses can be correlated with their position in the coal bed by comparing the sample numbers with the corresponding numbers of Fig. 14. These analyses show that this is an exceptionally clean coal considering that there was nothing excluded in taking these samples.

The three sections of the mine represented by channel samples I, II, and III are remarkably uniform, but the section represented by channel sample IV is considerably dirtier than the other three. There is no outstanding bench of the coal bed that is any better than any other bench. Increment sample IVb8, which is the only sample taken of the roof coal, indicates that this roof coal is some of the best in the mine, carrying only 3.4 per cent of ash. There are not enough data available to say whether this is true of a considerable portion of this top coal or whether it is a local condition. The only bottom sample taken, represented by increment sample IVb7, has an ash content of 10.5 per cent, which is less than the average for this face

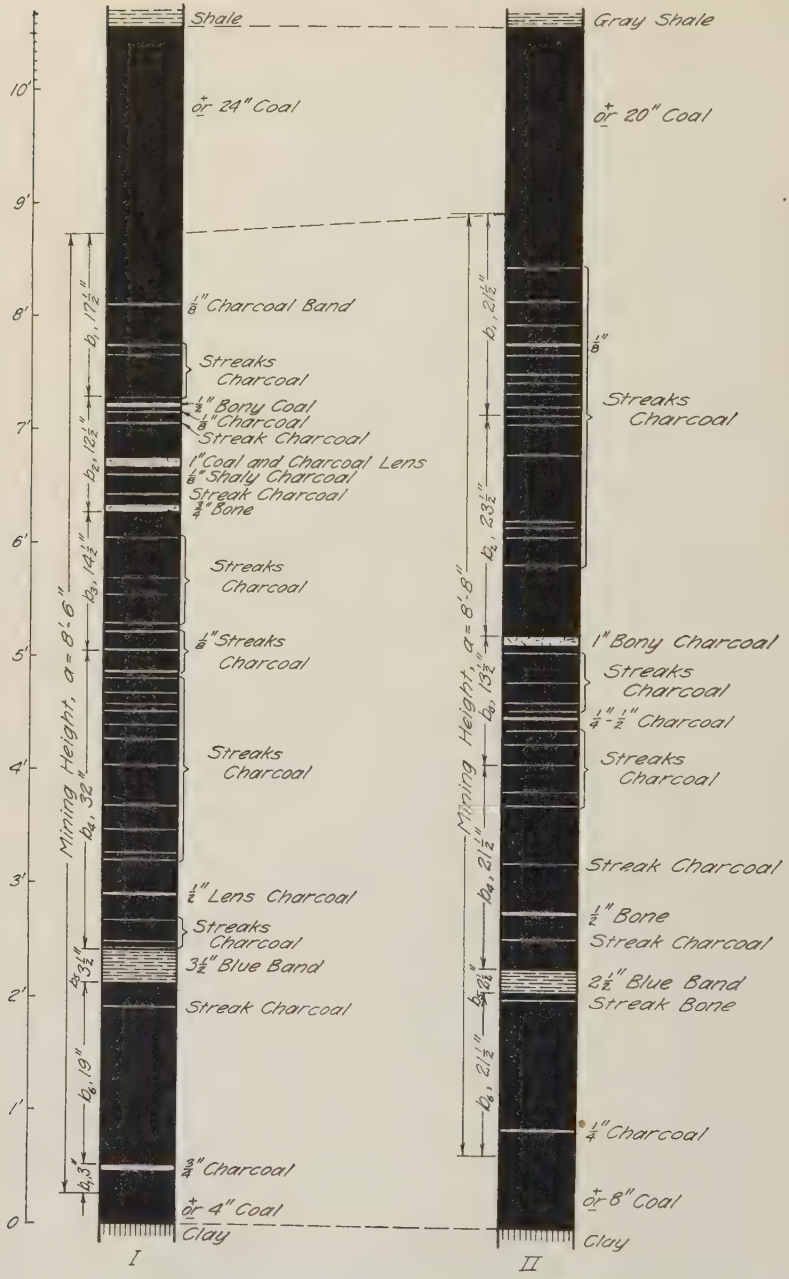

FIG. 14. FACE SECTIONS OF NO. 6 COAL, FRANKLIN COUNTY, MINE F

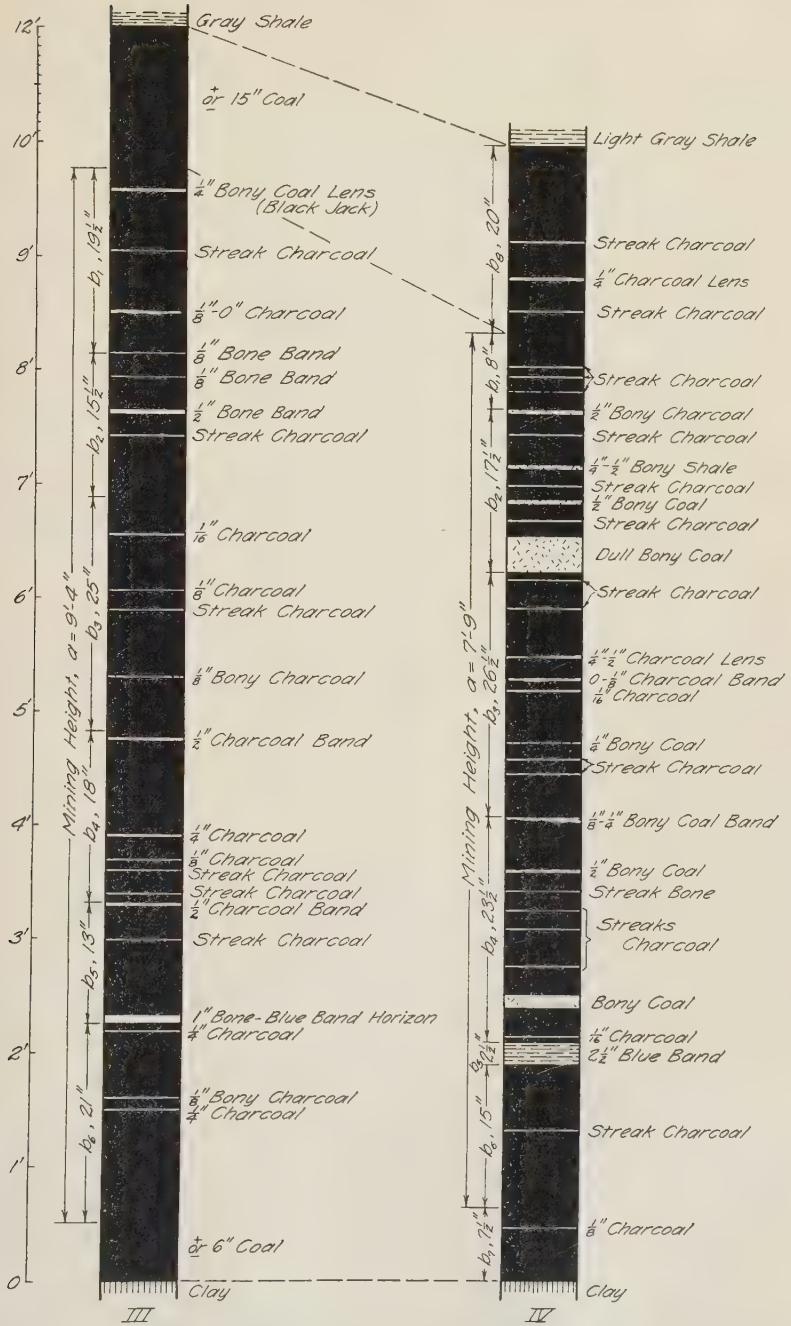

FIG. 14 (CONCLUDED). FACE SECTIONS OF NO. 6 COAL, FRANKLIN COUNTY, MINE F

Table 28

Analyses of Mine Samples—Mine F

As Received

Sample Number	Moisture	V. M.	F. C.	Ash	Total Sulphur	Sulphate Sulphur	Pyritic Sulphur	Organic Sulphur	Calculated B.t.u.	Softening Temperature of Ash deg. F.
FIa	10.95	30.61	49.73	8.71	0.65	0.01	0.09	0.55	11 450*	2234
FIIa	10.71	29.08	51.65	8.56	0.75	0.02	0.14	0.67	11 560*	
FIIIa	10.99	30.74	49.59	8.67	0.80	0.02	0.11	0.67	11 460*	
FIVa	9.98	28.37	48.00	13.66	0.71	0.02	0.10	0.59	10 900*	2576
FIb1	9.92	33.58	52.40	4.19	0.85	0.02	0.09	0.74	12 470	2296
FIb2	10.10	32.27	53.63	10.30	0.70	0.01	0.19	0.50	11 400	2562
FIb3	9.93	31.73	52.85	5.48	0.33	0.01	0.08	0.24	12 200	2234
FIb4	9.42	29.29	47.65	13.64	0.72	0.01	0.08	0.63	11 000	2576
FIb5	5.35	14.43	15.86	64.36	0.41	0.01	0.17	0.23	.....	2744
FIb6	10.29	29.15	52.98	7.58	1.08	0.03	0.53	0.60	11 800	2430
FIb7	11.37	30.19	48.16	11.78	0.59	0.02			11 040	1907
FIIb1	9.98	30.76	53.85	5.27	0.88	0.02	0.20	0.66	12 200	
FIIb2	11.14	29.98	54.95	3.93	1.07	0.03	0.20	0.84	12 260	
FIIb3	12.73	34.81	47.43	5.03	0.74	0.02	0.20	0.52	11 870	
FIIb4	13.37	28.06	51.76	6.81	0.88	0.02	0.07	0.77	11 240	
FIIb5	3.80	17.04	20.97	58.18	0.61	0.02	0.09	0.50	.....	
FIIb6	9.32	35.97	47.74	6.97	0.82	0.02	0.12	0.58	12 050	
FIIIb1	8.49	33.90	34.86	22.75	0.64	0.02	0.12	0.50	9 800	
FIIIb2	10.52	32.62	38.28	2.64	0.33	0.01	0.14	0.16	12 570	
FIIIb3	10.05	34.87	52.00	3.08	0.53	0.02	0.08	0.43	12 560	
FIIIb4	11.66	35.90	43.48	8.96	0.84	0.03	0.12	0.69	11 420	
FIIIb5	10.92	30.74	47.62	9.29	0.98	0.03	0.07	0.88	11 430	
FIIIb6	9.88	37.07	45.85	7.21	0.65	0.02	0.13	0.52	11 930	
FIVb1	10.64	34.35	50.89	4.12	0.83	0.02	0.14	0.67	12 450	2394
FIVb2	6.92	29.69	45.15	18.23	0.71	0.03	0.10	0.58	10 630	2688
FIVb3	9.78	35.73	48.44	6.05	0.58	0.02	0.08	0.48	12 100	2360
FIVb4	10.92	27.15	49.09	12.85	0.45	0.01	0.08	0.36	10 940	2547
FIVb5	4.30	21.25	4.47	69.99	0.35	0.01	0.15	0.18	.....	2772
FIVb6	9.09	35.75	48.51	6.65	0.94	0.02	0.24	0.68	12 130	2462
FIVb7	10.12	38.25	41.17	10.46	0.78	0.02	0.43	0.33	11 400	2050
FIVb8	12.49	29.94	54.18	3.39	0.70	0.02	0.20	0.48	12 160	2216

*Calorimeter determinations.
Suffix a indicates complete channel sample.
Suffix b indicates increment samples; see Fig. 14.

section. The mineral charcoal found in this mine may be a high grade coal or a very dirty one as found from ash analyses of three samples which showed 3.2, 9.6, and 36.2 per cent, respectively. It is probable that the greater percentage of the mineral charcoal has a high ash content due to its soft, porous nature which is favorable for the deposition of foreign material.

The average mine moisture is 10 per cent. The calorific value of this coal is high, averaging considerably more than 11 000 B.t.u. as mined.

The softening temperature of the coal ash varied from 1900 to 2700 deg. F., averaging about 2400 deg. F. This coal would fall in Class 2 which comprises those coals having ash of a medium fusibility.

The sulphur analysis in practically all samples was considerably under 1.00 per cent. The pyritic and sulphate sulphur analyses were very low in nearly every case. The bulk of the sulphur is in the organic form. The sulphur content of this coal is so low that there is no necessity for its removal.

Tipple Sample

This mine produces about 8000 tons of coal in an eight-hour day. The coal is screened into the following sizes, with these percentages made on the day the tipple sample was taken:

6-in. lump	12.61 per cent
6 × 3-in.	20.39 per cent
3 × 2-in.	12.12 per cent
2 × 1½-in.	5.03 per cent
1½ × ¾-in.	15.29 per cent
¾ × ⅜-in.	5.89 per cent
⅜ × 0-in.	28.67 per cent

The larger sizes were hand picked after leaving the shaking screens so that the sample had to be taken from the main feeder. A run-of-mine sample of 4100 pounds was taken for sizing and float-and-sink analysis.

Testing Procedure and Washability Analyses

Table 29 gives the weight percentages as well as the ash and sulphur content of the various sizes of the sample from this mine. The 6 x 3-in. egg size is the cleanest. There is a general increase in ash percentage in the finer sizes although this is not great until the 20 x 48 mesh size is reached. The average ash analysis for the total sample is slightly less than the average for the mine samples. This is accounted for because of the impurities that are separated while load-

TABLE 29

SCREEN ANALYSIS—MINE F

Sample P

Size	Weight per cent	Cumulative Weight per cent	Ash per cent (Moisture Free)	Sulphur per cent (Moisture Free)
6-in. lump	12.6	12.6	7.96	0.69
6 x 3 in.	20.4	33.0	7.08	0.86
3 x 1½ in.	17.1	50.1	8.26	0.86
1½ x ¾ in.	15.3	65.4	8.63	0.78
¾ x ⅜ in.	5.9	71.3	8.50	0.79
⅜ x ³⁄₁₆ in.	11.5	82.8	9.23	0.85
³⁄₁₆ in. x 10 mesh	5.8	88.6	8.74	0.92
10 x 20 mesh	4.6	93.2	8.03	0.78
20 x 48 mesh	4.0	97.2	12.38	0.81
48 x 100 mesh	1.2	98.4	14.42	0.84
100 x 200 mesh	0.6	99.0	14.90	0.87
200 x 0 mesh	1.0	100.0	14.45	0.85
Totals and averages	100.0		8.63	0.82

ing the coal underground such as the blue band and "black jack" impurities. The sulphur content of the various sizes is very constant with a variation of only 0.2 per cent, ranging from 0.7 to 0.9 per cent.

All sizes were subjected to a float-and-sink analysis except the 6-in. lump. A composite 48 x 0 mesh size was run for the three finest sizes. The results of this analysis are given in Table 30 and washability curves 45 to 53 inclusive, Fig. 15. From a study of these curves and tables it is apparent that this coal has very little free impurity of any kind in it. If washed, coal of as low as 5 per cent ash could be produced with a high recovery. Practically all of the sink material at 1.70 specific gravity is impurity free from adhering coal. The theoretical yield table, Table 31, was compiled at this gravity because of the sharp breaks in the curves for all sizes. This gives a refuse with an ash content of over 60 per cent for all sizes. Table 32 compiled from this theoretical yield table shows that only about 3 per cent of the coal as mined would be discarded to produce a cleaned coal having 7 per cent ash.

The sulphur is under one per cent for all fractions in all sizes and does not enter into the problem of cleaning.

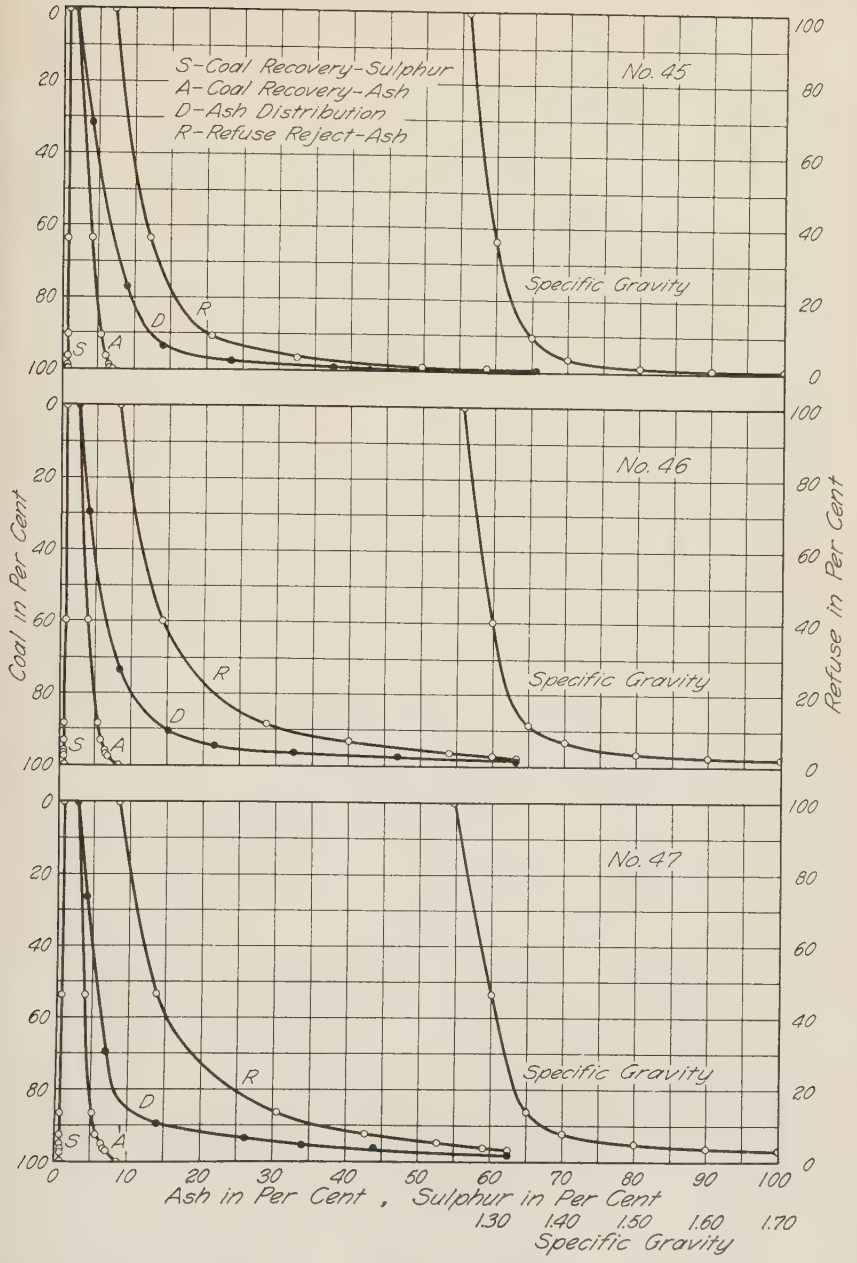

FIG. 15. WASHABILITY CURVES, MINE F, TIPPLE SAMPLE P

(Moisture Free)

Coal sizes: No. 45, 6 x 3 in.; No. 46, 3 x 1½ in.; No. 47, 1½ x ¾ in.

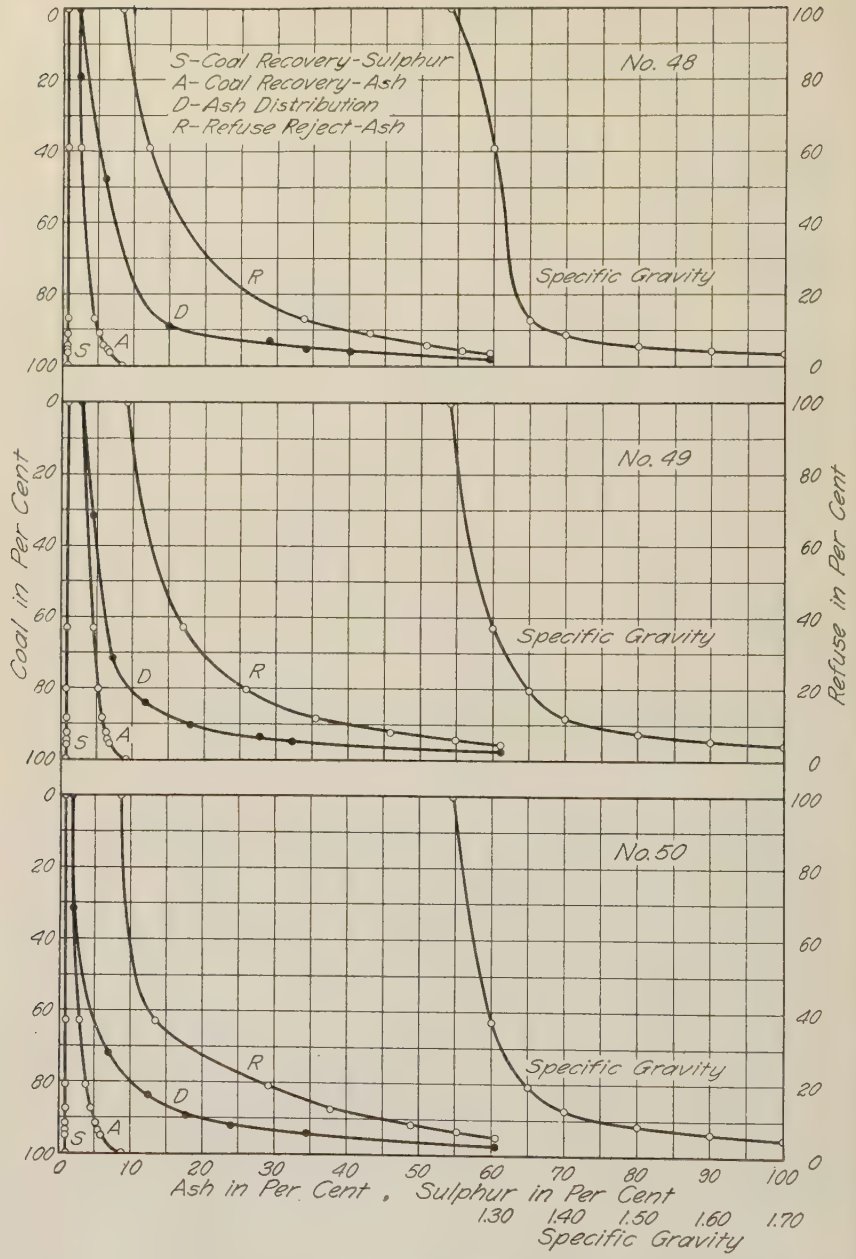

FIG. 15 (CONTINUED). WASHABILITY CURVES, MINE F, TIPPLE SAMPLE P

(Moisture Free)

Coal sizes: No. 48, 3/4 x 3/8 in.; No. 49, 3/8 x 3/16 in.; No. 50, 3/16 in. x 10 mesh.

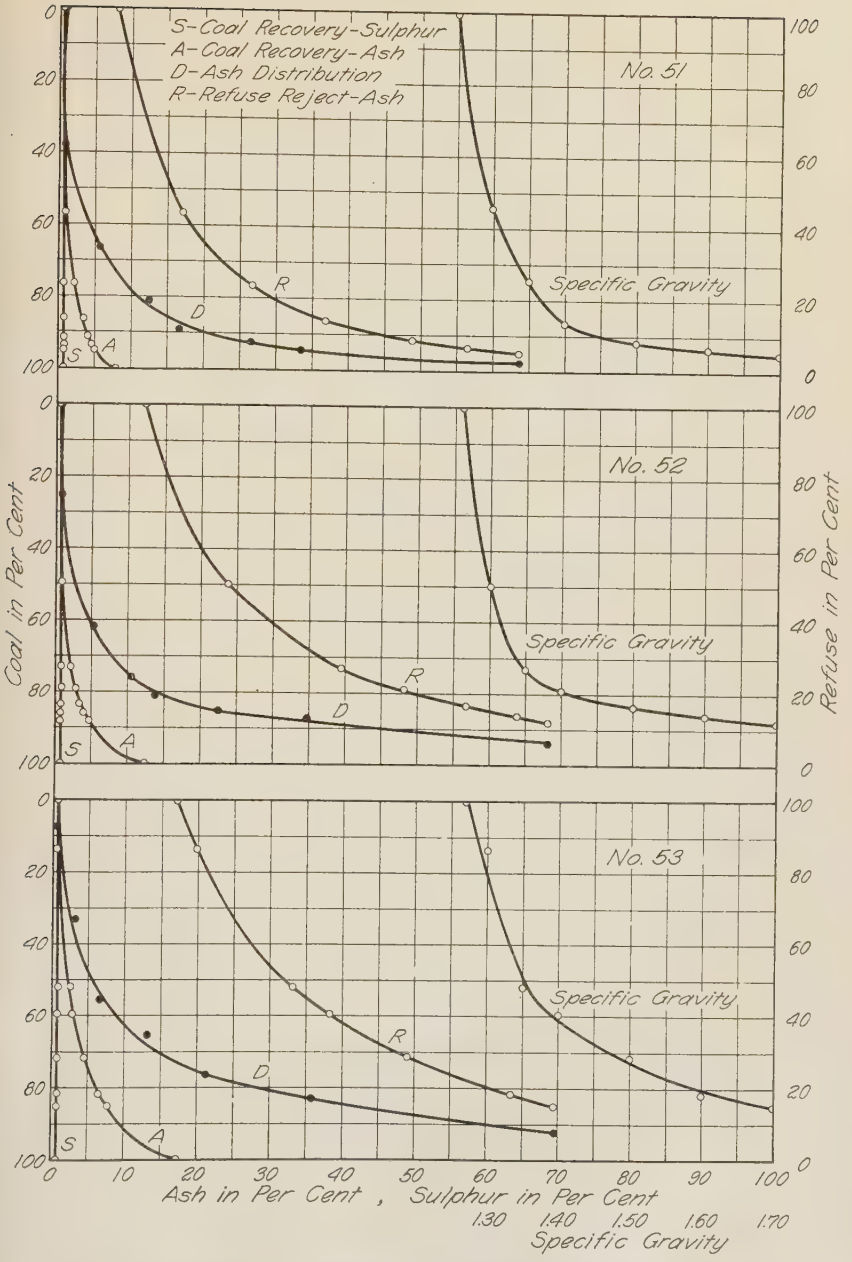

FIG. 15 (CONCLUDED). WASHABILITY CURVES, MINE F, TIPPLE SAMPLE P

(Moisture Free)

Coal sizes: No. 51, 10 x 20 mesh; No. 52, 20 x 48 mesh; No. 53, 48 x 0 mesh.

Table 30

Summary of Float-and-Sink Results—Mine F

Per cent by weight and per cent ash and sulphur in fractions at different specific gravities (moisture free)

Size	Per cent of Sample	<1.30 Sp. Gr.			1.30–1.35 Sp. Gr.			1.35–1.40 Sp. Gr.			1.40–1.50 Sp. Gr.			1.50–1.60 Sp. Gr.			1.60–1.70 Sp. Gr.			>1.70 Sp. Gr.			Total		
		Wt.	Ash	S	Wt.	Ash	S	Wt.	Ash	S	Wt.	Ash	S	Wt.	Ash	S	Wt.	Ash	S	Wt.	Ash	S	Wt.	Ash	S
6 x 3 in.	23.3	63.4	4.16	0.87	27.1	9.08	0.85	6.0	14.14	0.86	2.3	23.45	0.83	0.5	37.50	0.87	0.2	42.40	0.97	0.5	65.40	1.13	100	7.08	0.86
3 x 1½ in.	19.6	59.3	4.06	0.85	29.0	8.59	0.87	4.9	15.32	0.84	2.9	21.85	0.86	0.9	34.44	0.87	0.6	46.78	0.92	2.4	63.40	1.01	100	8.26	0.86
1½ x ¾ in.	17.5	53.4	4.14	0.76	33.1	6.97	0.78	5.8	14.12	0.80	2.9	26.20	0.83	1.2	34.08	0.83	0.7	43.90	0.86	2.9	62.62	0.94	100	8.63	0.78
¾ x ⅜ in.	6.7	39.0	2.64	0.78	47.8	6.27	0.78	4.3	15.10	0.84	3.2	28.98	0.84	1.3	34.21	0.84	0.9	40.30	0.88	3.5	59.65	0.95	100	8.50	0.79
⅜ x ³⁄₁₆ in.	13.2	63.0	4.50	0.81	17.2	7.32	0.96	8.1	11.93	0.84	4.3	18.15	0.86	1.8	27.90	0.87	1.3	32.32	0.89	4.3	61.07	0.93	100	9.23	0.85
³⁄₁₆ in. x 10 mesh	6.6	62.8	2.97	0.93	18.0	6.92	0.86	6.5	12.64	0.87	4.5	17.82	0.86	1.7	24.05	0.90	1.3	34.46	0.90	5.2	60.55	1.14	100	8.74	0.92
10 x 20 mesh	5.3	56.7	0.99	0.82	19.6	5.77	0.75	9.9	12.57	0.67	5.2	16.76	0.67	2.1	26.40	0.79	1.6	33.56	0.80	4.9	63.94	0.89	100	8.03	0.78
20 x 48 mesh	4.6	49.6	0.86	0.77	23.4	5.39	0.79	6.2	10.47	0.44	4.1	13.75	0.75	2.9	22.67	0.75	1.8	34.75	0.98	12.0	68.38	1.17	100	12.38	0.81
48 x 0 mesh	3.2	13.7	0.27	0.66	38.2	3.16	0.76	7.7	6.41	0.83	12.1	13.15	0.83	9.7	21.30	0.85	3.2	35.82	0.89	15.4	69.50	0.92	100	17.24	0.80
6 x 0 in.	100.0	56.5	3.69	0.83	27 8	7.45	0.83	6.2	13.27	0.81	3.6	20.41	0.83	1.2	35.60	0.85	0.9	38.00	0.89	3.5	64.13	1.00	100	8.73	0.84
6-in. Lump	12.6																						100	7.96	0.69
6 x 0 in.	87.4																						100	8.73	0.84
Total R. O. M.	100.0																						100	8.63	0.82

TABLE 31

THEORETICAL YIELDS—MINE F

(6 x 0-in. Coal—Moisture Free)

Size	Per cent of Total	Raw Coal		Yield per cent		Separation at Sp. Gr.	Coal		Refuse	
		Ash per cent	S per cent	Coal	Refuse		Ash	S	Ash	S
6 x 3 in.	23.3	7.1	0.9	99.5	0.5	1.70	6.8	0.9	65.4	1.1
3 x 1½ in.	19.6	8.3	0.9	97.6	2.4	1.70	6.9	0.9	63.4	1.0
1½ x ¾ in.	17.5	8.6	0.8	97.1	2.9	1.70	7.0	0.8	62.7	0.9
¾ x ⅜ in.	6.7	8.5	0.8	96.5	3.5	1.70	6.6	0.8	59.7	0.9
⅜ x 3/16 in.	13.2	9.2	0.9	95.7	4.3	1.70	6.9	0.9	61.1	0.9
3/16 in. x 10 mesh	6.6	8.7	0.9	94.8	5.2	1.70	5.9	0.9	60.6	1.2
10 x 20 mesh	5.3	8.0	0.8	95.1	4.9	1.70	5.2	0.8	63.9	0.9
20 x 48 mesh	4.6	12.4	0.8	88.0	12.0	1.70	4.8	0.8	68.3	1.2
48 x 0 mesh	3.2	17.2	0.8	84.6	15.4	1.70	7.7	0.8	69.5	0.9

Data relating to raw coal samples tested are as follows:

COAL FROM MINE F, TIPPLE SAMPLE P

Washability Curve No.	Size	Raw Coal			Lightest Coal		
		Ash per cent	Sulphur per cent	Moisture per cent	Sp. Gr.	Ash per cent (Moisture free)	Sulphur per cent
45	6 × 3 in.	6.4	0.77	10.0	1.262	1.80	0.84
46	3 × 1½ in.	7.5	0.77	10.0	1.259	2.65	0.875
47	1½ × ¾ in.	7.7	0.70	10.0	1.248	2.93	0.852
48	¾ × ⅜ in.	7.6	0.71	10.0	1.241	2.31	0.83
49	⅜ × 3/16 in.	8.3	0.76	10.0	1.241	2.87	0.894
50	3/16 in. × 10 mesh	7.8	0.83	10.0	1.247	1.94	0.841
51	10 × 20 mesh	7.2	0.70	10.0	1.251	0.592	0.814
52	20 × 48 mesh	11.2	0.73	10.0	1.264	0.495	0.812
53	48 × 0 mesh	15.5	0.72	10.0	1.271	0.38	0.802

Table 33 gives the variation in coal ash softening temperature of the various float-and-sink fractions for the 1½ x ¾-in. coal. The fusion point of the refuse is slightly higher than that of the clean coal for this size.

Conclusions

This coal is a very clean coal as mined and it is doubtful whether any further cleaning by mechanical means would be justifiable. However, if so desired, a coal of very low ash content for Illinois coals could be produced.

TABLE 32

YIELDS FROM 1000 TONS OF RUN-OF-MINE COAL—MINE F

Coal, Not Cleaned						Coal, Cleaned						Total Coal Yield per cent	Refuse	
Size	Tons	M*	Ash	S	B.t.u.	Size in.	Tons	M*	Ash	S	B.t.u.		Tons	Per Cent
6-in. Lump.....	126	10.0	7.2	0.6	12 040	6 x 0	843	10.0	6.0	0.8	12 210	96.9	31	3.1
3-in. Lump.....	330	10.0	6.7	0.7	12 100	3 x 0	647	10.0	5.9	0.8	12 220	97.0	30	3.0
3-in. Lump.....	330	10.0	6.7	0.7	12 100	3 x ⅜	368	10.0	6.2	0.8	12 170	97.0	30	3.0
						⅜ x 0	279	10.0	5.6	0.8	12 260			

*The analyses are for a moisture content of 10.0 per cent, the average moisture in the coal as mined. The moisture in the cleaned coal will depend upon the method of cleaning used.

TABLE 33

SOFTENING TEMPERATURE OF ASH OF SELECTED FLOAT-AND-SINK FRACTIONS—MINE F

Size	Fraction	Softening Temperature of Ash deg. F.
1½ x ¾ in.	1.30 Float	2296
	1.30–1.35 Float	2505
	1.35–1.40 Float	2360
	1.40–1.50 Float	2216
	1.50–1.60 Float	2216
	1.60–1.70 Float	2240
	1.70 Sink	2475
1½ x ¾ in.	1.50 Float	2318
	1.50 Sink	2446

20. *Mine G, Coal No. 5, Williamson County.*—The coal is hard but not as hard as the No. 6 coal in this same field. There is a high percentage of bright coal. There is very little mineral charcoal, and it is found as thin streaks along the bedding planes. This is unusual since most Illinois coal beds contain a considerable amount of this type of coal, generally of the soft friable variety. The mineral charcoal in this bed is fairly hard. The bedding planes in this coal are farther apart than generally found in Illinois coal. Since the coal naturally breaks free along bedding planes, this condition aids in the production of the lump size of coal. There is also a fairly pronounced cleat in this coal which assists in breaking out the coal. The bed varies in thickness from 44 to 50 inches, with an average of about 46 inches.

There are no characteristic bands of impurities separating the coal into certain definite benches as in the No. 6 and No. 7 coals.

Impurities

Most of the impurities associated with this coal are thin streaks of bone, shale, and pyrite along the bedding planes. These at times enlarge to lenses. There is some vertical deposition of fine veinlets of pyrite. They may start at the roof or any position in the bed, branch out fan-shaped, and end as abruptly as they started. Some fine flakes of calcite and gypsum are deposited along vertical cleavage planes. Very little bony coal is present. A few thin streaks are found along the bedding planes.

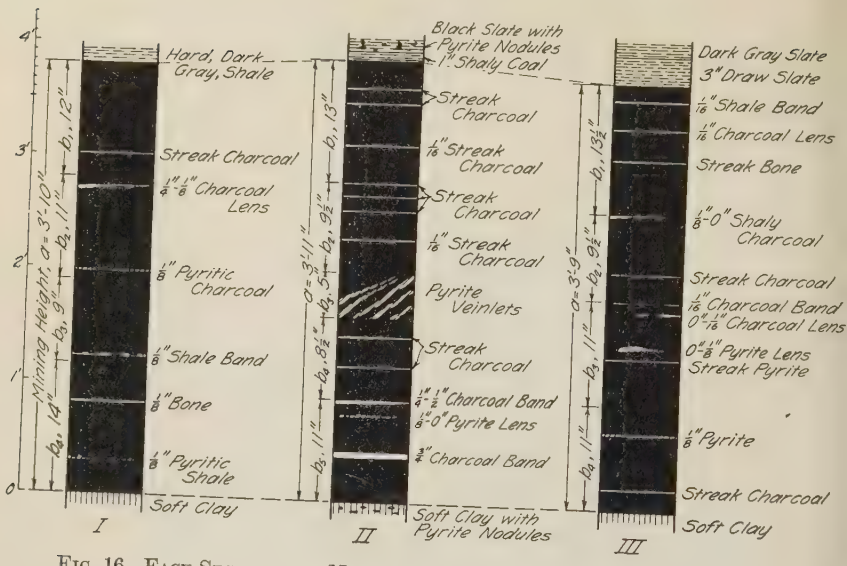

FIG. 16. FACE SECTIONS OF NO. 5 COAL, WILLIAMSON COUNTY, MINE G

The roof overlying this coal is exceptionally good. It is a hard, black slate which withstands weathering very well. Occasionally there is a thin rash of draw slate about 2 inches in thickness that falls when the coal is shot down and becomes mixed with the coal to a certain extent. In general the coal breaks freely from the roof rock.

The floor is a soft light, clay with some pyrite balls or concretions in it.

Mine Samples

Three complete channel samples were taken with a set of increment samples for each, as shown in Fig. 16. These samples were located in the north, west, and east sides of the mine.

Table 34 gives the analyses of the mine samples. The chief facts of interest concerning this coal are its low moisture content and high calorific value. It has a lower moisture content than any of the other coals tested. The average heating value of this coal is higher than that of the coal from any of the other mines, approaching close to 12 000 B.t.u. as mined. It has an average ash content of about 11 per cent. The sulphur percentage is also high, being nearly 4 per cent.

The top of this bed seems to have the cleanest coal. In all of the face sections except one increment in face section III, the top part of

TABLE 34

ANALYSES OF MINE SAMPLES—MINE G

As Received

Sample Number	Moisture	V. M.	F. C.	Ash	Total Sulphur	Sulphate Sulphur	Pyritic Sulphur	Organic Sulphur	Calculated B.t.u.	Softening Temperature of Ash deg. F.
GIa	6.19	36.19	47.22	10.40	3.31	0.26	1.73	1.32	12 160*	2218
GIIa	7.37	34.41	45.36	12.86	4.09	0.32	2.56	1.21	11 520*	2130
GIIIa	6.83	34.81	48.09	10.27	3.47	0.44	2.12	0.91	11 990*	
GIb1	6.13	36.24	48.59	9.04	2.49	0.23	1.31	0.95	12 540	2216
GIb2	9.21	34.07	47.09	9.63	4.91	0.30	3.37	1.24	11 900	2294
GIb3	7.41	35.38	46.96	10.25	2.80	0.43	0.87	1.50	12 150	2252
GIb4	7.87	34.05	44.09	13.99	2.72	0.23	1.47	1.02	11 480	2180
GIIb1	7.84	36.58	47.63	7.95	2.81	0.43	0.76	1.62	12 480	2198
GIIb2	7.42	35.73	45.07	11.78	5.07	0.42	3.29	1.36	11 880	2100
GIIb3	8.01	31.35	38.05	22.59	10.52	1.27	7.89	1.36	9 780	2430
GIIb4	9.68	32.89	42.92	14.51	5.52	0.42	3.67	1.43	11 000	2030
GIIb5	8.57	32.57	42.81	16.05	3.94	0.33	2.42	1.19	10 980	2080
GIIIb1	4.23	35.89	47.33	12.55	3.89	0.35	2.20	1.34	12 200	
GIIIb2	7.51	35.38	49.09	9.02	2.68	0.21	1.43	1.04	12 460	
GIIIb3	9.36	34.35	44.64	11.65	4.23	0.38	2.05	1.80	11 540	
GIIIb4	9.53	32.63	45.75	12.09	2.30	0.32	1.03	0.95	11 530	

*Calorimeter determinations.
Suffix a indicates a complete channel sample.
Suffix b indicates increment samples; see Fig. 16.

the bed was considerably lower in ash than the bottom of the bed. This generalization cannot be made for the sulphur content since it is irregular in the three sections sampled.

The sulphate sulphur is considerably higher for this mine than for the other mines sampled, one increment sample containing 1.27 per cent of this form of sulphur. The organic sulphur content is fairly constant and varies from about one-tenth to one-half of the total sulphur present. The greatest variation is noticed in the pyritic sulphur analyses, which follow very closely the ups and downs in the percentages of total sulphur.

The softening temperature of the coal ash from these mine samples varies from 1968 to 2430 deg. F. This coal is therefore classed as having ash of a low fusion point, or as Class 3.

Tipple Sample

This mine produces the following sizes in the approximate percentages given:

6-in. lump	24 per cent
6 × 3-in. egg	21 per cent
3 × 2-in. nut	14 per cent
2-in. screenings	40 per cent

A run-of-mine sample of 2600 pounds was taken for analysis at the laboratory.

TABLE 35

SCREEN ANALYSIS—MINE G

Sample P

Size	Weight per cent	Cumulative Weight per cent	Ash per cent (Moisture Free)	Sulphur per cent (Moisture Free)
6-in. lump	24.6	24.6	11.67	4.38
6 x 3 in.	19.2	43.8	11.85	4.90
3 x 1½ in.	19.5	63.3	12.46	6.49
1½ x ¾ in.	12.7	76.0	12.61	4.35
¾ x ⅜ in.	9.1	85.1	12.41	4.24
⅜ x 3/16 in.	5.4	90.5	14.32	3.44
3/16 in. x 10 mesh	2.9	93.4	16.35	3.66
10 x 20 mesh	2.4	95.8	19.39	3.89
20 x 48 mesh	2.2	98.1	22.30	3.52
48 x 100 mesh	1.0	99.0	26.08	3.61
100 x 200 mesh	0.4	99.4	25.14	4.05
200 x 0 mesh	0.6	100	30.70	4.05
Totals and averages	100		13.11	4.76

Testing Procedure and Washability Analyses

That this coal stands up well in preparation is evident from the screen analysis, Table 35. Over 90 per cent of the coal is above 3/16 inch. The 6-in. lump heads the list of sizes produced. The other sizes gradually become less with only 0.6 per cent of 200-mesh material. The average ash percentages gradually increase with decrease in size of coal, the 6-in. lump being the lowest and the 200 mesh coal the highest in ash. There is a concentration of sulphur in the 3 x 1½-in. size. The other sizes have about the same sulphur content.

All of the sizes listed were subjected to float-and-sink treatment except the 6-in. lump and the three finest sizes which were run as a composite 48 x 0 mesh. Ash and sulphur determinations were made on these three finest sizes as given in Table 35. The results of the float-and-sink analyses are summarized in Table 36 and expressed graphically in washability curves 54 to 62 inclusive, Fig. 17. It is apparent from a study of these curves that all of the sizes lend themselves to treatment with a substantial decrease in ash, at 90 per cent recovery for the largest sizes and for the finer sizes at 1.70 specific gravity irrespective of recovery. The 6 x 3-in. egg does not show as good washability characteristics as the finer sizes.

Data relating to raw coal samples tested are as follows:

Coal From Mine G, Tipple Sample P

Washability Curve No.	Size	Raw Coal: Ash per cent	Raw Coal: Sulphur per cent	Raw Coal: Moisture per cent	Lightest Coal: Sp. Gr.	Lightest Coal: Ash per cent (Moisture free)	Lightest Coal: Sulphur per cent (Moisture free)
54.....	6 × 3 in.	10.9	4.52	7.6	1.267	2.02	1.25
55.....	3 × 1½ in.	11.5	6.00	7.6	1.255	2.13	1.45
56.....	1½ × ¾ in.	11.6	4.05	7.6	1.255	1.93	1.40
57.....	¾ × ⅜ in.	11.4	3.91	7.6	1.249	1.10	1.22
58.....	⅜ × 3/16 in.	13.2	3.17	7.6	1.251	1.38	1.42
59.....3/16 in.	× 10 mesh	15.1	3.37	7.6	1.245	1.14	2.11
60.....	10 × 20 mesh	17.8	3.59	7.6	1.239	1.27	1.70
61.....	20 × 48 mesh	20.6	3.24	7.6	1.231	1.13	2.33
62.....	48 × 0 mesh	24.4	3.44	7.6	1.231	1.32	2.06

A coal of any desired ash content could be produced as long as it was within the range of the values given on the A curves. The theoretical yields as given in Table 37 were selected primarily to give an ash content of between 9 and 10 per cent. The 6 x 3-in. size does not lend itself so well to cleaning, but only a small amount of free refuse at about 98 per cent recovery would give a good appearing coal with an ash content of 10.6 per cent. Table 38, made up from the theoretical yield table, gives the results that could be expected from treating 1000 tons of this coal. With a yield of over 93 per cent, a

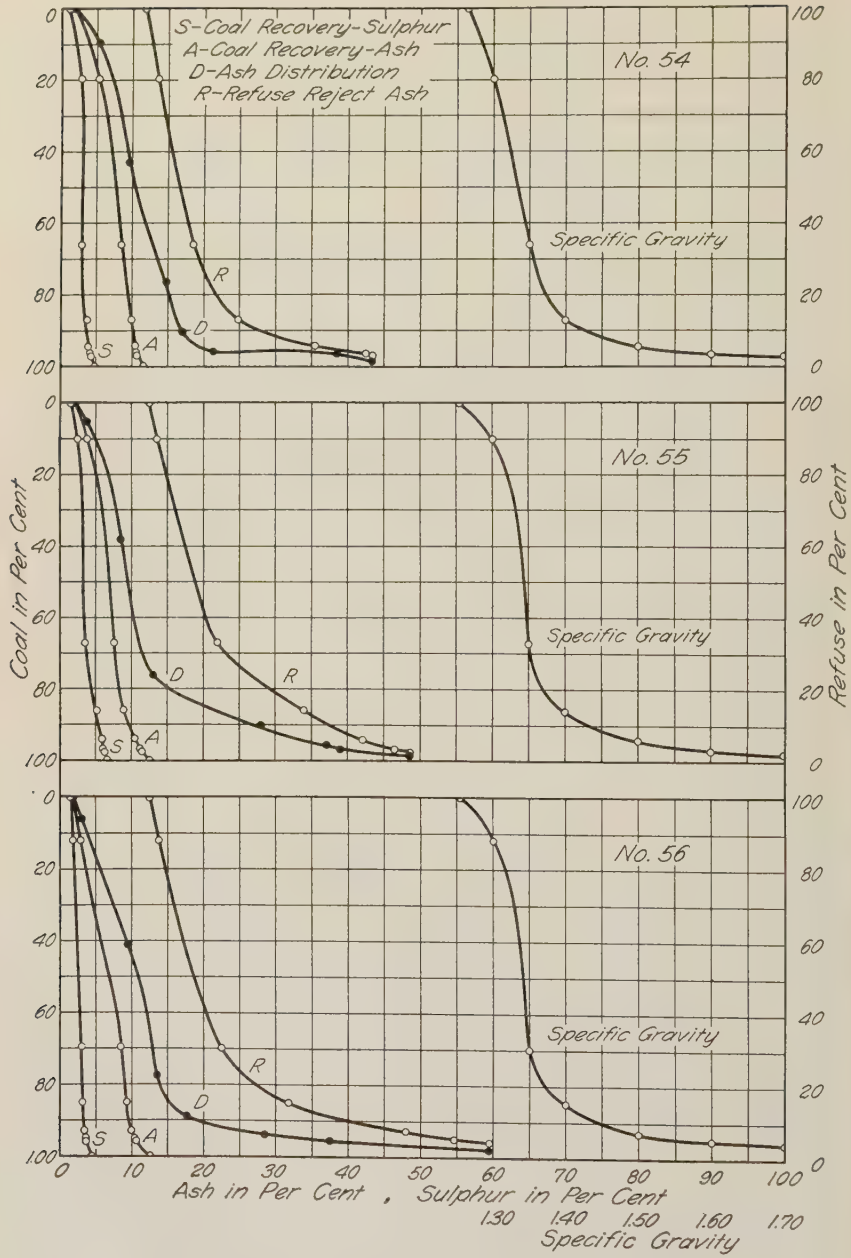

FIG. 17. WASHABILITY CURVES, MINE G, TIPPLE SAMPLE P

(Moisture Free)

Coal sizes: No. 54, 6 x 3 in.; No. 55, 3 x 1½ in.; No. 56, 1½ x ¾ in.

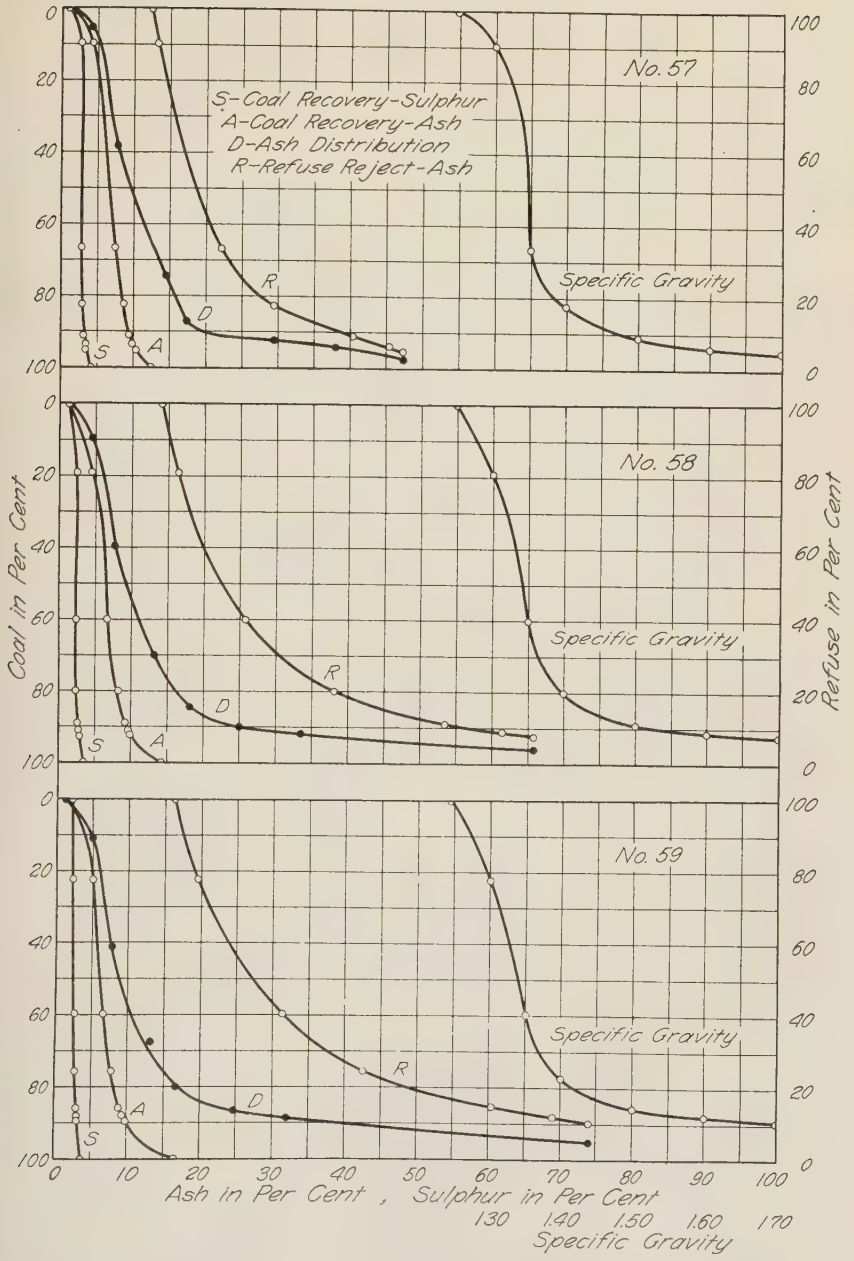

FIG. 17 (CONTINUED). WASHABILITY CURVES, MINE G, TIPPLE SAMPLE P

(Moisture Free)

Coal sizes: No. 57, ¾ x ⅜ in.; No. 58, ⅜ x 3/16 in.; No. 59, 3/16 in. x 10 mesh.

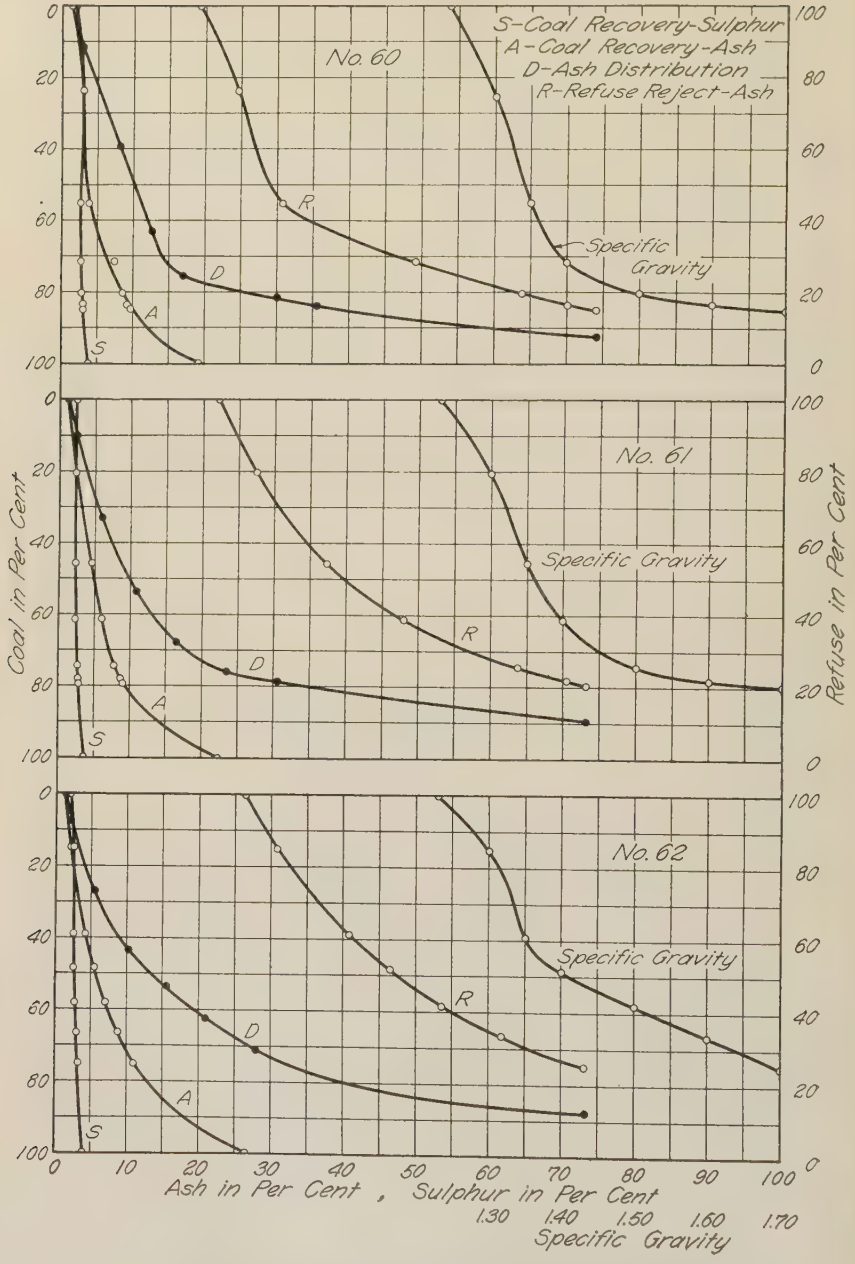

FIG. 17 (CONCLUDED). WASHABILITY CURVES, MINE G, TIPPLE SAMPLE P

(Moisture Free)

Coal sizes: No. 60, 10 x 20 mesh; No. 61, 20 x 48 mesh; No. 62, 48 x 0 mesh.

TABLE 36

SUMMARY OF FLOAT-AND-SINK RESULTS—MINE G

Per cent by weight and per cent ash and sulphur in fractions at different specific gravities (moisture free)

Size	Per cent of Sample	<1.30 Sp. Gr.			1.30–1.35 Sp. Gr.			1.35–1.40 Sp. Gr.			1.40–1.50 Sp. Gr.			1.50–1.60 Sp. Gr.			1.60–1.70 Sp. Gr.			>1.70 Sp. Gr.			Total		
		Wt.	Ash	S	Wt.	Ash	S	Wt.	Ash	S	Wt.	Ash	S	Wt.	Ash	S	Wt.	Ash	S	Wt.	Ash	S	Wt.	Ash	S
6 x 3 in.	25.5	19.5	5.25	2.75	46.7	9.68	3.28	20.8	14.73	5.55	7.5	17.09	8.50	1.8	21.42	12.28	0.9	38.50	15.42	2.8	43.69	24.37	100	11.85	4.90
3 x 1½ in.	25.9	10.0	3.85	2.67	57.1	8.46	3.66	18.9	13.14	11.52	8.2	28.12	12.60	2.6	37.25	14.57	0.7	39.00	18.26	2.5	48.61	16.76	100	12.46	6.49
1½ x ¾ in.	16.9	12.2	3.02	1.78	57.6	9.52	3.32	15.5	13.40	3.51	7.9	17.84	6.85	1.7	28 61	7.77	1 1	37.51	8.36	4.0	59.48	22.85	100	12.61	4.35
¾ x ⅜ in.	12.0	9.6	4.31	2.77	56.8	7.94	2.83	16.3	14.42	4.30	8.4	17.54	5.61	2.5	29 67	8.92	1.3	38.21	11.14	5.1	47.48	16.24	100	12.41	4.24
⅜ x 3/16 in.	7.2	19.0	4.56	2.61	41.2	7.70	2.54	19.8	13.28	2.74	8.8	18.25	4.53	2.3	25.21	6.56	1.2	33 68	8.30	7.7	65.75	9.14	100	14.32	3.44
3/16 in. x 10 mesh	3.9	22.5	4 95	2.23	37.2	7.42	2.76	15.7	12.91	3.62	10.0	16.45	4.56	2.8	24.50	7.32	1.4	31.81	7.50	10.4	73.80	7.64	100	16.35	3.66
10 x 20 mesh	3.2	23.7	2.80	2.73	31.2	8.14	2.34	16.4	12.50	3.10	9.0	17.13	4.77	3.1	30.19	7.62	1.7	35.65	7.58	14.9	74.20	8.14	100	19.39	3.89
20 x 48 mesh	2.9	20.4	2.39	2.37	25.4	6.10	2.19	15.5	10.74	2.70	12.9	16.59	4.05	3.7	23.42	4.45	1.4	30.53	5.31	20.7	73.25	6.30	100	22.30	3.52
48 x 0 mesh	2.5	15.0	2.07	2.41	23.9	5.55	2.68	9.8	10.28	2.69	9.4	15.54	4.08	8.6	21.10	4.24	8.4	27.94	4.82	24.9	73.32	5.28	100	27.26	3.73
6 x 0 mesh	100.0	14.8	3.60	2.53	50.0	8.73	3.23	18.0	13.70	7.23	8.3	20.00	8.00	2.4	28.47	10.10	1.2	35.50	10.70	5.3	60.8	13.7	100	13.38	9.84
6-in. Lump	24.6																						100	11.67	4.38
6 x 0 in.	75.4																						100	13.58	4.89
Total R. O. M.	100.0																						100	13.11	4.76

TABLE 37

THEORETICAL YIELDS—MINE G

(6 x 0-in. Coal—Moisture Free)

Size	Per cent of Total	Raw Coal		Yield per cent		Separation at Sp. Gr.	Coal		Refuse	
		Ash per cent	S per cent	Coal	Refuse		Ash	S	Ash	S
6 x 3 in.	25.5	11.9	4.9	98.0	2.0	1.58	10.6	4.2	41.0	22.2
3 x 1½ in.	25.9	12.5	6.5	90.0	10.0	1.43	9.7	5.2	38.0	12.7
1½ x ¾ in.	16.9	12.6	4.4	90.0	10.0	1.44	9.8	3.2	40.0	13.5
¾ x ⅜ in.	12.0	12.4	4.2	90.0	10.0	1.48	9.3	3.2	39.6	13.4
⅜ x 3/16 in.	7.2	14.3	3.4	90.0	10.0	1.54	9.4	2.6	56.8	9.0
3/16 in. x 10 mesh	3.9	16.4	3.7	90.0	10.0	1.70	9.5	3.2	73.8	7.6
10 x 20 mesh	3.2	19.4	3.9	85.1	14.9	1.70	9.8	3.1	74.2	8.1
20 x 48 mesh	2.9	22.3	3.5	79.3	20.7	1.70	9.0	2.8	73.3	6.3
48 x 0 mesh	2.5	27.3	3.7	75.1	24.9	1.70	11.0	3.2	73.3	5.3

clean coal would be produced of about 9 per cent ash. This would necessitate discarding only 67 tons of refuse for every 1000 tons of coal produced.

The calorific value of the cleaned coal is higher than any of the other coals tested, although the cleaned coal from Mine F is only slightly lower.

There can be very little sulphur reduction. Table 39 gives the analyses of the various sulphur forms made on the float-and-sink fractions of the 1½ x ¾-in. coal. There is a concentration of sulphate and pyritic sulphur in the heavier fractions. There is, however, a high organic as well as a fairly high pyritic sulphur percentage in the lighter fractions.

Either the raw coal or cleaned coal from this mine has an ash with a low softening temperature, Class 3, as judged by the 1½ x ¾-in. coal.

Conclusions

This coal lends itself readily to cleaning processes. A substantial reduction in ash can be made at a high recovery for all sizes, but no marked sulphur reduction could be expected.

TABLE 38

YIELDS FROM 1000 TONS OF RUN-OF-MINE COAL—MINE G

Coal, Not Cleaned						Coal, Cleaned						Total Coal Yield per cent	Refuse	
Size	Tons	M*	Ash	S	B.t.u.	Size	Tons	M*	Ash	S	B.t.u.		Tons	Per Cent
6-in. Lump.....	246	7.6	10.8	4.0	11 980	6 x 0 in.	688	7.6	9.1	3.6	12 270	93.4	66	6.6
3-in. Lump.....	438	7.6	10.9	4.3	11 970	3 x 0 in.	495	7.6	8.9	3.5	12 300	93.3	67	6.7
3-in. Lump.....	438	7.6	10.9	4.3	11 970	3 x ⅜ in.	369	7.6	8.9	3.8	12 280	93.3	67	6.7
						⅜ x 0 in.	126	7.6	8.9	2.6	12 340			

*The analyses are for a moisture content of 7.6 per cent, the average moisture in the coal as mined. The moisture in the cleaned coal will depend upon the method of cleaning used.

TABLE 39

SULPHUR DISTRIBUTION AND SOFTENING TEMPERATURE OF ASH OF SELECTED FLOAT-AND-SINK FRACTIONS—MINE G

(Moisture Free)

Size	Fractions	Sulphate Sulphur	Pyritic Sulphur	Organic Sulphur	Total Sulphur	Softening Temperature of Ash deg. F.
1½ x ¾ in.	1.30 Float	0.05	0.72	1.03	1.78	2030
	1.30–1.35 Float	0.08	1.38	1.86	3.32	2248
	1.35–1.40 Float	0.12	2.34	1.05	3.51	2302
	1.40–1.50 Float	0.14	4.87	1.84	6.85	2248
	1.50–1.60 Float	0.32	6.62	0.83	7.77	1849
	1.60–1.70 Float	0.48	6.32	1.56	8.36	2252
	1.70 Sink	0.70	18.85	3.30	22.85	2562
1½ x ¾ in.	1.50 Float					2075
	1.50 Sink					2366

21. *Mine H, Coal No. 5, Peoria County.*—The mine was not sampled so no data are available for the coal as mined. The sample for float-and-sink analysis was taken from a carload of 2-in. lump coal used in a boiler test at the University of Illinois. This sample

TABLE 40

SCREEN ANALYSIS—MINE H

Sample P

Size	Weight per cent	Cumulative Weight per cent	Ash per cent	Sulphur per cent
			(Moisture Free)	
+1 in.*	31.9	31.9		
1 x ½ in.	48.3	80.2		
½ x ⅜ in.	13.1	93.3		
⅜ x 3/16 in.	5.0	98.3		
3/16 x 0 in.	1.7	100.0		
Total	100.0			
Float and Sink Sizes				
+½ in.	80.2	80.2	10.22	4.89
½ x 0 in.	19.8	100.0	10.99	4.52
Total and averages	100.0		10.43	4.84

*This sample was taken after passing through a crusher set at approximately 1 inch.

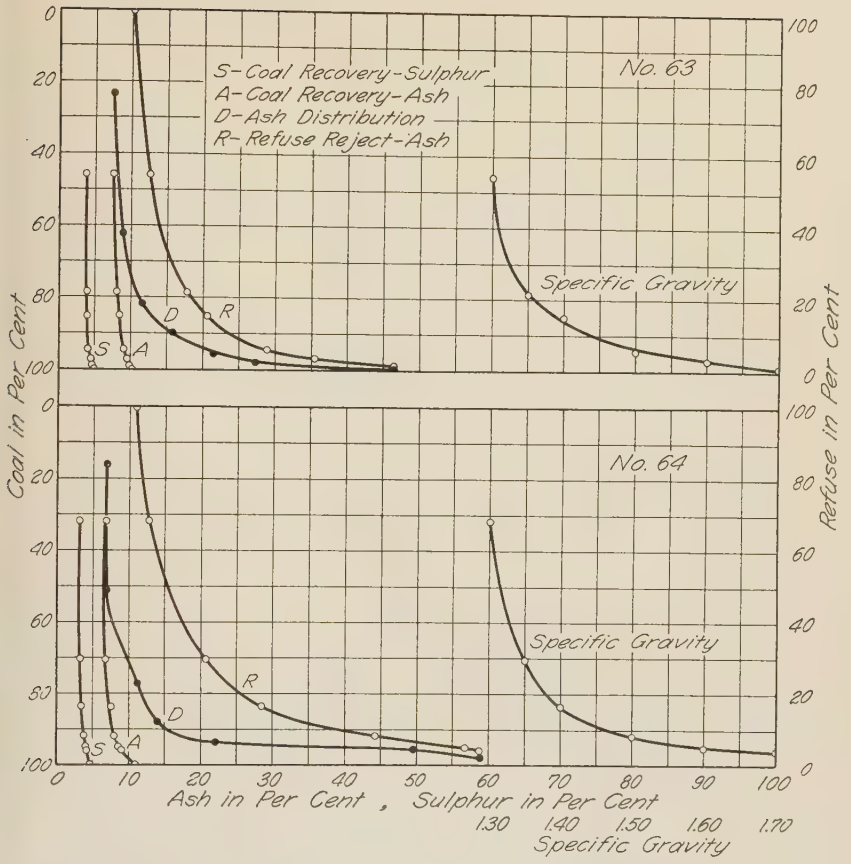

FIG. 18. WASHABILITY CURVES, MINE H, TIPPLE SAMPLE P
(Moisture Free)
Coal sizes: No. 63, +½ in.; No. 64, −½ in.

was taken after the coal had passed through a crusher set at 1 inch. Table 40 is therefore a screen analysis of this crushed lump and is no indication of the sizes this mine produces. A considerable amount of coal coarser than 1 inch passed through the crusher.

Test Procedure and Washability Analyses

The sizes from the screen analyses were combined to give two samples for float-and-sink analysis, a + ½-in. and ½ x 0-in. size. The + ½-in. size is therefore crusher size 1 inch x screen size ½ inch. The average ash and sulphur analyses for these samples are given in Table 40. The sulphur is high, being nearly 5 per cent.

Table 41

Summary of Float-and-Sink Results—Mine H

Per cent by weight and per cent ash and sulphur in fractions at different specific gravities (moisture free)

Size	Per cent of Sample	<1.30 Sp. Gr.			1.30–1.35 Sp. Gr.			1.35–1.40 Sp. Gr.			1.40–1.50 Sp. Gr.			1.50–1.60 Sp. Gr.			1.60–1.70 Sp. Gr.			>1.70 Sp. Gr.			Total		
		Wt.	Ash	S	Wt.	Ash	S	Wt.	Ash	S	Wt.	Ash	S	Wt.	Ash	S	Wt.	Ash	S	Wt.	Ash	S	Wt.	Ash	S
+½ in.....	80.2	45.6	7.62	3.72	32.9	8.84	4.29	6.4	11.66	4.64	9.8	15.92	7.51	2.5	21.58	11.62	1.6	27.34	14.42	1.2	46.70	18.94	100	10.22	4.89
—½ in.....	19.8	31.8	6.92	3.28	38.7	6.90	3.48	13.2	11.22	4.19	8.5	13.92	6.88	2.8	22.15	11.31	1.1	49.44	12.08	3.9	58.79	13.83	100	10.99	4.52
Total Sample..	100*	42.8	7.53	3.67	34.1	8.40	4.11	7.7	11.51	4.50	9.6	15.57	7.40	2.6	21.73	11.54	1.5	30.27	14.07	1.7	55.12	17.70	100	10.43	4.84

*Original sample was not a complete tipple sample but was from a car of 2-inch lump.

TABLE 42

THEORETICAL YIELDS—MINE H

(Moisture Free)

Size	Per cent of Total	Raw Coal		Yield per cent		Separation at Sp. Gr.	Coal		Refuse	
		Ash per cent	S per cent	Coal	Refuse		Ash	S	Ash	S
+½ in.*	80.2	10.2	4.9	98.8	1.2	1.70	9.8	4.7	46.7	18.9
½ x 0 in.	19.8	11.0	4.5	96.1	3.9	1.70	9.1	4.1	58.8	13.8

*Coal that has passed through a crusher set at 1 inch and over a ½-in. round hole screen.

TABLE 43

YIELDS FROM 1000 TONS OF 2-IN. LUMP COAL CRUSHED TO 1 INCH—MINE H

Size	Coal, Cleaned					Total Coal Yield per cent	Refuse	
	Tons	M*	Ash	S	B.t.u.		Tons	Per Cent
1 x 0 in.	983	15.6	8.1	3.9	11 160	98.3	17	1.7

*The analyses are for a moisture content of 15.6 per cent, the approximate moisture in the coal as mined. The moisture percentage was not determined accurately as in the case of the other coals tested; but is an average obtained from published analyses of this coal. The moisture in the cleaned coal will depend upon the method of cleaning used.

Table 41 and washability curves 63 and 64, Fig. 18, give the summary of the float-and-sink analyses. The ½ x 0-in. coal shows good cleaning characteristics. Either size could be cleaned to produce a coal of about 9 per cent ash with a high recovery. Table 42 gives some arbitrarily selected yields, while these same yields are expressed in terms of yields per 1000 tons in Table 43. This is an excellent coal for this field. The cleaned coal has a calorific value of slightly over 11 000 B.t.u. The ash percentage of this cleaned coal would be about 8 per cent and the sulphur percentage about 4.

Data relating to raw coal samples tested are as follows:

COAL FROM MINE H, TIPPLE SAMPLE P

Washability Curve No.	Raw Coal				Lightest Coal		
	Size	Ash per cent	Sulphur per cent	Moisture per cent	Sp. Gr.	Ash per cent (Moisture free)	Sulphur per cent (Moisture free)
63	+½ in.	8.63	4.13	15.6	.....	....	....
64	−½ in.	9.28	3.81	15.6	.....	....	....

Conclusions

This is naturally a good coal, and it is questionable whether there would be enough benefit derived from cleaning to warrant the operation. In making any conclusions on this sample, it must be considered only as a crushed lump sample. The finer sizes produced are more than likely considerably higher in ash than this sample since that is characteristic of practically all of the coal produced in Illinois. These finer sizes could probably be benefited to a great extent by being cleaned.

22. *Summary and Conclusions.*—It is impossible to give briefly a complete summary of this investigation that would include all matters of interest. However, a very general summary of the washability of these coals can be made by comparing the yields and analyses of the separation products made at selected specific gravities. This comparison is given in Table 44. While it is true that these separation points are somewhat arbitrary, yet for the purpose of comparing the several coals they are quite logical. The names assigned to the three separation products—clean coal, middlings, and refuse—are expressive of the character of these products, for the refuse is worthless from a fuel standpoint, the clean coal is as low in ash as would be justified by the yield, and the middling is an intermediate product that would have to be crushed and retreated if it were to be worth anything.

For comparison, the results are given on a moisture-free basis so the percentages of ash and sulphur are somewhat higher numerically than if they were given on an as-mined or as-received basis. (In studying the data in this report, the reader should notice that all curves and some of the tables are on a moisture-free basis, but that in some cases analyses are given on a mine-moisture basis to show channel samples or final products.) Since Mine H was not sampled the correct moisture content of the coal bed is not known, but the figure given is an average obtained from published analyses of mine samples.

A more complete and detailed summary as to the washability of each coal may be found in the tables "Theoretical Yields" and "Yields from 1000 Tons Run of Mine Coal," prepared for each coal. The comparisons shown in Table 44, however, indicate in a general way the relative washability of these coals. It is quite clear that recoveries of from about 75 to 85 per cent will give a clean coal, for all but two mines, that will contain less than 10 per cent ash (dry basis). The as-mined coal from Mine F is as low in ash and much lower in sulphur than any of the washed coal from the other mines. The coal from

TABLE 44

COMPARISON SUMMARY OF FLOAT-AND-SINK RESULTS—ALL MINES

Per cent by weight and per cent ash and sulphur in clean coal, middlings, and refuse (moisture free)

Coal Field	Coal Bed	Mine	Size in.	Clean Coal <1.40 Sp. Gr.			Middlings 1.40-1.70 Sp. Gr.			Refuse >1.70 Sp. Gr.			Total			Coal Bed Moisture	Unit Coal B.t.u.
				Wt.	Ash	S	Wt.	Ash	S	Wt.	Ash	S	Wt.	Ash	S		
LaSalle County...	5	A	5 x 0	83.3	9.1	3.50	10.0	28.7	7.20	6.7	62.4	20.60	100	14.8	4.97	12.3	14 450
Marshall County.	7	B	6 x 0	77.1	14.4	3.34	12.4	28.8	5.51	10.5	66.0	18.50	100	23.1	5.20	15.6	14 630
Peoria County....	5	C	6 x 0	84.8	14.0	3.29	10.1	33.3	5.85	5.1	56.0	7.64	100	18.5	3.77	16.5	14 610
LaSalle County...	2	E	5 x 0	82.3	8.7	3.93	8.3	26.8	9.52	9.4	62.3	16.27	100	15.2	5.57	12.4	14 740
Franklin County..	6	F	6 x 0	90.5	5.5	0.83	6.0	24.7	0.87	3.5	64.1	1.00	100	8.7	0.84	9.8	14 530
WilliamsonCounty	5	G	6 x 0	82.8	8.9	3.77	11.9	23.2	8.73	5.3	60.8	13.71	100	13.4	4.89	7.6	15 000
Peoria County....	5	H	2-in. lump*	84.6	8.2	3.92	13.7	18.4	8.90	1.7	55.1	17.70	100	10.4	4.84	15.6	14 610

*Crushed to 1 in. crusher size prior to treatment.

Mine H, a sample from a car of 2-in. lump, was also relatively low in ash.

A glance at Table 44 shows large percentages of sulphur in the clean coal, except, of course, from Mine F. This investigation brings out very clearly the fact that, excluding Mine F, none of the coal from the mines that were sampled can be made to yield a low-sulphur coal by any preparation or washing process. A study of the float-and-sink summary tables shows that, even with coal as fine as 20 mesh, the sulphur in the 1.30-float product is almost always greater than 2.25 per cent and in only one or two cases is less than 2.00 per cent. Indeed, early in the investigation it became evident that a low-sulphur coal could not be obtained, again excepting Mine F, for the average organic sulphur in the channel samples ranged from about 1.2 per cent for Mine G to 1.8 per cent for Mine A (1.3 per cent to 2.0 per cent, dry basis). Since organic sulphur is not removable by any known process, it must be clear that the lowest sulphur percentage that can be obtained by any washing process is the percentage of organic sulphur that is in the coal.

If all the pyrite were in lump form and could be freed by crushing then a clean coal with approximately the limiting percentage of sulphur (the per cent of organic sulphur) could be produced, but it is well known that some of the pyrite is present in microscopic particles, averaging about $\frac{1}{500}$ inch and less in diameter. Crushing even to 200 mesh would not free all of this material so it is obvious that even the finest float coal will show pyritic sulphur. While no determinations of pyritic sulphur were made on the finest material, yet the results on the sizes tested prove the point. On 10 x 20-mesh, 1.30 specific gravity float coal from Mines B, C, and E the percentages of pyritic sulphur were 0.61, 0.38 and 0.86 respectively, with higher percentages in the float coal from the heavier-gravity solutions.

In all coals but those from Mine F, a large amount of sulphur will remain after preparation and washing, due to high organic sulphur and inseparable pyrite.

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